Resource mapping of open loop systems

Deliverable D.T2.2.2 Synopsis of geothermal mapping methods

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Introduction

Glossary of terms and units

As some of the screened studies and literature use slightly different terms for describing the potential of use associated to open loop systems, the subsequent Table 1 shows parameter definitions applied in this report. It also intends to harmonize them. Table 2 shows terms and physical units used in the equations shown in this report.

Table 1: Glossary of terms and abbreviations

Term	Definition
ATES	Aquifer Thermal Energy Storage based on natural or artificial aquifers. ATES based on artificial storage is not within the scope of GeoPLASMA-CE.
Open loop system	Energetic use of groundwater for heating and cooling based on well doublets and groundwater based heat pumps (case of heating or forced cooling), see also chapter 0. *Further synonyms*: groundwater heat pumps, thermal groundwater use.
Potential, potential of use, resource	Energy content of a groundwater body accessible for energetic use. In this report, the terms resource and potential of use will be primarily used.
Well doublet	Set of two wells for extracting (production well) and injecting (reinjection well) of groundwater for thermal use.
Aquifer	Groundwater bearing geological unit.

Table 2: Summary of physical terms and units

Symbol	Physical term	Unit
P	Thermal capacity (thermal power)	W
Q	Yield, pumping rate of a well	m^3/s
ΔT	Temperature shift between the production and the injection well	K
cp	Specific heat capacity	J/kg/K

Symbol	Physical term	Unit
ρ	Density	Kg/m^3
$<cp.\rho>$	Volumetric heat capacity	$J/m^3/K$
H	Heat (thermal energy)	J
W	Thermal work	Wh
τ	Total operational period of an already existing or planned open loop system	s
m	Hydraulically effective (net) aquifer thickness	m
kf	Hydraulic conductivity	m/s
R	Hydraulic range of influence of a well	m
r_{well}	Radius of a well	m
i	Hydraulic gradient	m/m
a	Distance between production and injection well	m
yr	Year	a
A	Area of real estate	m^2
Indices applied		
aquifer	Of aquifer	
area_balanced	Given area for heating and cooling (balanced use)	
area_unbalanced	Given area for heating or cooling (unbalanced use)	
leg	Legal	
max	Maximum capacity at peak load	
mean	Mean value	
MGW	Average groundwater table derived from groundwater observation wells at a given date.	

Symbol	Physical term	Unit
NGW	Low groundwater table derived from groundwater observation wells at a given date.	
tot	total	
water	Of water	

The aim of the GeoPLASMA-CE project is to develop new management strategies for shallow geothermal use of urban and non-urban regions. The project intends to create a standardized data base and a web-based platform including the geothermal potential as well as factors of risk and land-use conflicts. The data comprises geological and structural data, petrophysical and technical parameters as well as the model data produced during different stages of the project. The geothermal potential modelling and the risk-factor validation will be based on a 3D structural model of the shallow geological subsurface which will be used to quantify the spatial distribution of physical and technical parameters and of risk factors.

To elaborate a compilation and assessment of existing methods a literature study was conducted as first step to establish a workflow for geothermal modelling in GeoPLASMA-CE. Information about existing methods for geothermal mapping of current and previous projects for 3D-modelling, open loop and closed loop systems as well as land-use-conflict mapping was gathered. The applicability of the methods used in the projects for GeoPLASMA-CE was investigated in a next step. The project team created a template to summarize the most important information about the methods regarding the topics mentioned (3D-modelling, open loop and closed loop systems, land-use-conflict mapping). Summaries of all methods and lessons learned from the projects, which provide important inputs, were established for four separate reports, based on these standardized assessment sheets:

- Synopsis of geological 3D-modelling methods,
- Synopsis of geothermal mapping methods - open loop systems,
- Synopsis of geothermal mapping methods - closed loop systems,
- Synopsis of mapping methods of land-use conflicts and environmental impact assessment.

All assessment sheets are added in annex 1 for further information. The publications concerning the analysed projects were collected and are available for further research and use in the database "knowledge repository" (Table 7).

This process generated important knowledge about how to develop workflows of geothermal mapping for GeoPLASMA-CE, which will be accomplished within the next steps.

The delivered four reports and the knowledge repository will be available online at the project's website (http://www.interreg-central.eu/Content.Node/GeoPLASMA-CE.html).

Scope of this report

This report is related to the Activity A.T2.2 "Research and compilation of existing mapping and assessment methods" and intends to give a summary of state of the art workflows of resource mapping related to the use of open loop systems. Results from previous and currently ongoing international as well as national projects are summarized and compared in this synopsis and rated for their applicability in GeoPLASMA-CE. This report in turn represents the basis for the compilation of harmonized workflows for mapping in GeoPLASMA-CE, which will be performed in the Activity A.T2.3.

Description of shallow geothermal use based on open loop systems

In this chapter, the principals of shallow geothermal use based on open loop systems will be sketched. In case of heating of buildings, the utilization of open loop systems requires the following components: (a) *Production well* to extract groundwater, (b) *injection well* for reverting the energetically used groundwater into the groundwater body, (c) *heat exchanger* to separate the primary circle (groundwater) form the secondary circle (heating and/or cooling system of the building), (d) *heat pump* for shifting the temperature level between the primary and secondary circle, (e) a *short term technical heat storage* to buffer peak loads and (f) a *low temperature based heating system* and / or a *moderate cooling system* in the building to be supplied. The components are also sketched in the subsequent Figure 1.

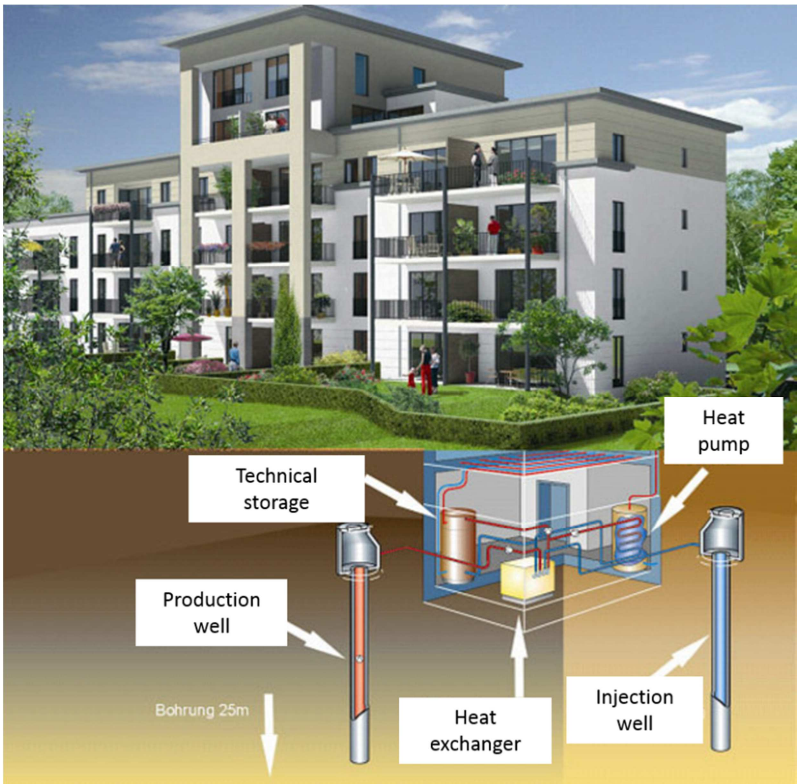

Figure 1: General sketch of an open loop system used for heating of buildings. ***Taken from*** *http://www.geothermie.de/wissenswelt/geothermie/technologien/oberflaechennahe-geothermie.html* ***(edited)***.

For using the heat stored or storable in the groundwater, a set of at least two regular groundwater wells (well doublet) are needed. The production well extracts the groundwater. After the thermal use of the groundwater it is obliged in most countries to inject it into the same groundwater body in order to sustain the aquifer pressure (injection well). For high capacity uses also well fields consisting of more than two wells are applied in order to reduce the pumping- and flow rate at individual wells. In many countries, groundwater based energetic use is limited to the uppermost aquifer if not used for drinking water supply.

For security and environmental protection reasons, it is necessary to hydraulically disconnect the groundwater circle from the heating or cooling circle by installing a heat exchanger.

The total energy produced for heating or forced cooling of a building consists of the heat provided by the groundwater body (anergetic part of the energy produced) and the heat provided /dumped[1] by the heat pump (exergetic[2] part of the energy production). The relation between the anergetic and exergetic part is described by the Coefficient of Performance (COP) for a certain moment in time or by the Seasonal Performance Factor (SPF) based on an annual balance. Normally, the SPF varies between 3 and 5, which means that for one unit of consumed electricity 3 to 5 units of anergetic heat are shifted to a higher temperature level.

In case of free cooling the heat pump and the technical storage (components –c- and –e-) are not used and both COP and SPF cannot be applied (set to infinity). As shallow geothermal energy use based on open loop systems is very efficient for constant base load supply it is recommended to install short term (24 hours) heat storages to supply daily peak loads. These storages normally represent technical storage systems based on water tanks, which are installed in the facility management room of buildings. Applying short term storages avoid fluctuations of pumping rates at the wells and fluctuations flow rates in the aquifer, respectively, which may damage the screen section of the wells.

Normally, open loop systems are used to either heat or cool buildings or technical processes. However, from an energetic point of view, an alternating seasonal use for heating and cooling leads to a better performance of the utilization and to a lower thermal impact on the groundwater body. The use of natural aquifers for seasonal heat storage is strongly depending on the aquifer flow velocity (Darcy velocity) and is only feasible if the distance of the production and reinjection well is set accordingly to the half-year flow distance of the groundwater. Seasonal heat storage is summarized in the term Aquifer Thermal Energy Storage (ATES). **However, ATES based on engineered artificial aquifers is not within the scope of GeoPLASMA-CE!**

General workflows for shallow geothermal resource and conflict mapping

In the framework of GeoPLASMA-CE, mapping focuses on (a) *estimation of resources* and (b) *conflicts of use and environmental impacts*. We will only focus on the currently two most common methods of utilization:

- Borehole heat exchangers (closed loop systems)

[1] In case of forced cooling

[2] Conversion of electric power or any other high enthalpy energy source into heat

- Groundwater based heat pumps (open loop systems)

All other systems shown in Figure 2 will not be considered in the project.

As the mapping of resources and conflicts of use of the above-mentioned methods of utilization base on similar input parameters, consider the same volume of the subsurface and partly rely on each other, we decided to show a general workflow scheme on all mapping and assessment issues relevant for GeoPLASMA-CE (see Figure 3).

As shown in Figure 3 the assessment and compilation of geoscientific datasets describing the geological and the hydrogeological situation of the near surface underground including possible anthropogenic influences (e.g. location of subsurface installations) represent the fundament of mapping. Geometrical information about the build-up of the subsurface (e.g. stratigraphic units and fault zones) feed a structural 3D model, which represents the next major working step (for more information on existing methods see **D.T2.2.1**). The structural model has to be parameterized with the physical parameters needed to solve the equations describing the geothermal potential. The parameterized models can then be used to calculate the potential of use either by processing relevant input data for estimating the resources or by direct calculation of resources for closed and open loop systems (see **D.T2.2.2**). In GeoPLASMA-CE, resource calculation can be performed on both 2D- and 3D data models. The choice of the appropriate geometrical dimension is depending on the quality and quantity of available input data and the aimed output parameter. However, the calculated potentials will be primarily displayed in terms of 2D datasets displayed at the project related web platform (WPT1). In addition, some of the planned web based visualization and data query routines will directly found on 3D data models.

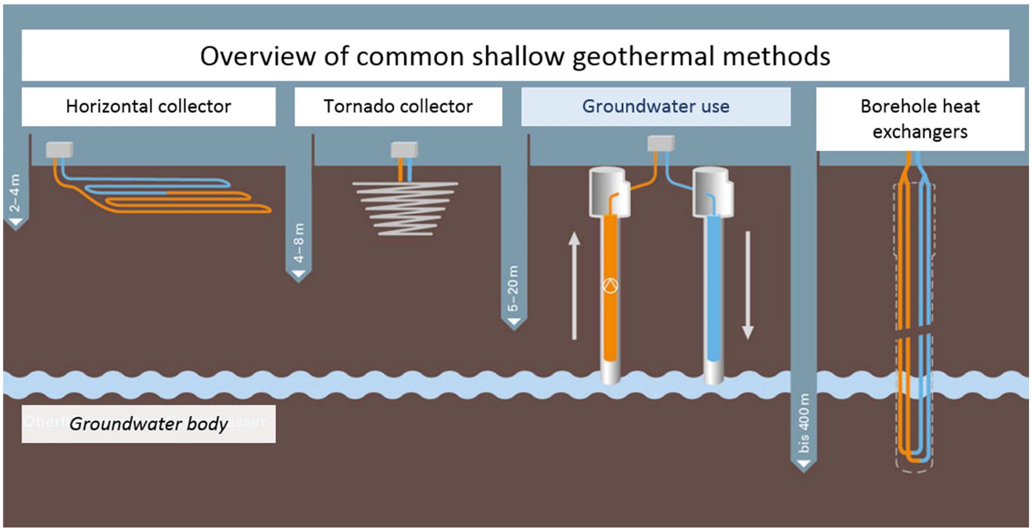

Figure 2: Overview of common shallow geothermal methods. ***All methods except for groundwater use represent "closed loop" systems. Graph taken from: https://www.energieatlas.bayern.de[3], edited.***

[3] Internet source: https://www.energieatlas.bayern.de/thema_geothermie/oberflaeche/nutzung.html, last access on March 17, 2017.

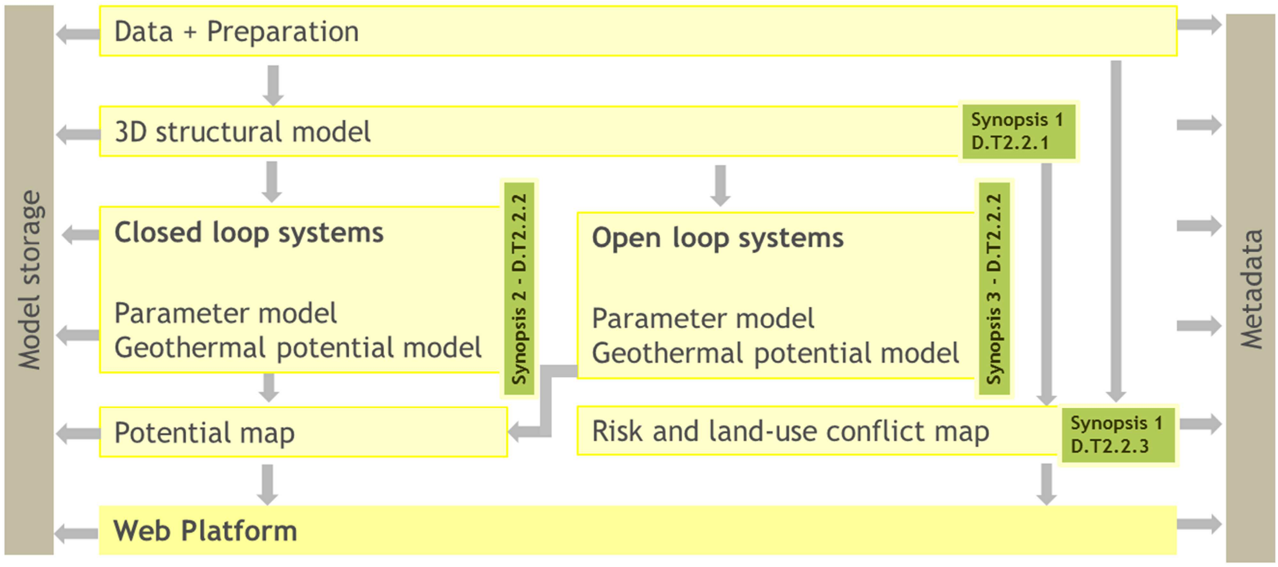

Figure 3: General sketch of the overall workfow and relations between modeling and mapping issues relevant for GeoPLASMA-CE. ***This sketch also shows the deliverables of A.T2.2 dealing with the different topics****.*

For all aspects of conflict of land-use, which are affected by a specific depth intervals (e.g. maximum drilling depths allowed or the position of a sensitive aquifer or subsurface installation), mapping will also strongly rely on a structural 3D modelling. Numerical process models, which also rely on 3D structural models, will be additionally applied for estimating negative interactions between competing shallow geothermal energy uses in regions with high density of utilization. Numerical process models (combined thermal- and hydraulic transport processes) can also be used to validate models based on data interpolation or to replace those in case of low quality / quantity input data. For more information on existing workflows for mapping of land-use conflicts see deliverable **D.T2.2.3**.

As indicated in Figure 3 emphasize also has to be put on a good and transparent documentation of data sources and workflows leading to output datasets. This includes a harmonized metadata documentation of used input data and a harmonized concept for geodata management including data storage.

Concepts to guarantee a sound output data documentation will be elaborated in activity **A.T2.3** (“Set-up of harmonized methods for assessment and mapping”).

Overview of screened projects

The literature study conducted did not only included projects inside the GeoPLASMA-CE project area, but also included international as well as national European projects. For that purpose published reports were examined and summarized in a so called “Knowledge Repository”. This repository will later be published on the GeoPLASMA-CE web platform and consists of (1) a referenced abstract of the respective publications in English language and (2) the whole publication in terms of a PDF report in case the specific document is publically available. For further information on unpublished, grey literature, a contact person is nominated at the published abstract.

This report was prepared based on the studies listed in Table 3. The Rep. ID indicates the ID number of the report in the Knowledge Repository. The literature study unfolded six projects, which are of interest for resource mapping of open loop systems at GeoPLASMA-CE. The assessment sheets of the investigated projects can be found in **Annex 1** of this report.

Table 3: Projects screened for the assessment of existing mapping methods of shallow open loop systems. Rep. ID indicates the ID number of the report in the knowledge repository.

Project	Country	Rep. ID
Mapping the low enthalpy geothermal potential of shallow Quaternary aquifers in Finland	Finland	1
Study on the shallow geothermal potential maps of Vienna (WC-31)	Austria	7
Geothermal Resource Map of Ireland	Ireland	13, 14, 62
A screening tool for open-loop ground source heat pump schemes	Great Britain	16
Geothermal resources in Slovenia	Slovenia	17
IIOG-S - Assessment of the shallow geothermal potential for the state of Salzburg (SC-27)	Austria	22
IOG - Information system on shallow geothermal energy, Bavaria	Germany	54
Potential map for an integrative management of open loop systems in Aspern Nord	Austria	65

Many states of Germany provide potential maps for shallow geothermal energy (e.g. Baden-Württemberg, Bavaria and Saxony) and one information system is also covering the deep geothermal potential of the country (GeotIS, www.geotis.de). The Bavarian web map service (www.lfu.bayern.de/geologie/geothermie_iog/) also considers open loop systems. In contrast, the other German web based information systems on shallow geothermal energy use screened, only consider resources associated to closed loop systems. However, shallow aquifers are included for visualizing environmental and technical risks associated to the use of closed loop systems (e.g. ISONG - isong.lgrb-bw.de/).

Regional resource maps available in Austria consider open loop systems for the City of Vienna and the state of Salzburg.

Geothermal maps for open loop systems are amongst others available for the following countries in northern and western Europe:

- Great Britain developed a screening tool for open loop ground source heat pump schemes in England and Wales.

- Ireland also provides a map to estimate the geothermal potential for open loop systems throughout the country.
- An overview about the amount of heat exploitable of the different aquifers was established for the entire country of Finland.

The project team tried to screen all relevant international studies currently ongoing or executed during the recent past. It also included national studies executed in the countries or regions involved in GeoPLASMA-CE. However, ongoing and past projects in countries with well-developed markets of shallow geothermal energy use like Switzerland, France and Sweden have not be included in this survey due to lack of access to literature. If relevant, results of studies from these countries will be included in updated versions of this document or in the deliverable **D.T2.5.1** (“Catalogue of success criteria for a sustainable management of shallow geothermal use”).

For mapping strategies concerning the assessment and visualization of conflicts of use and environmental risks related to open loop systems, please refer to deliverable **D.T2.2.3** (“Synopsis of mapping methods for land-use conflicts and environmental impact assessment”).

Definition of resources related to open loop systems

In general, geothermal resources can be reported in terms of:

- Thermal capacity of a well doublet (installed power),
- Energy content of a defined area (thermal work or energy available per year).

In the subsequent chapters, we will give a more detailed explanation on the above mentioned different characterization of potentials. Finally, we will link the screened projects to the different kind of resources characterization.

Thermal capacity

The thermal capacity (P) refers to a single well-doublet and can be described using the following equation (Eq.1).

$$P = Q * \Delta T * \langle cp * \rho \rangle \qquad \text{Eq. 1}$$

The thermal capacity is the product of the hydraulic productivity, reflecting the available pumping rate (Q) of a groundwater well doublet, and the thermal productivity reflecting the temperature difference (ΔT) between the production and injection well and of the volumetric heat capacity of the energetically used groundwater (can be set to 4200 $kJ/m^3/K$ for simplification reasons).

It describes the thermal power (for heating and cooling) of a well doublet for a certain moment or period. Usually, it delineates the maximum capacity with respect to the hydrogeological and thermal settings at the aquifer used. The relation between the thermal capacity and the energy consumption is shown in Figure 4 and Eq. 3. In that context, the operational period at a certain capacity level (peak load, base load or on a daily or annual basis) has to be taken into consideration to derive the energy from the thermal capacity.

Energy content available for utilization

Other approaches concerning geothermal potential of open loop systems focus on the energy content available in shallow aquifers to extract or drain heat. In opposite of describing potentials in terms of thermal capacity, the assessment of energy contents available allows to define the energy already consumed by existing use in terms of a heat balance. The energy content available in a defined volume of a groundwater body can be described with the following heat balance:

$$Heat\ Utilizable =$$
$$Heat\ Aquifer + \sum\left(\int_{t,0}^{1\ year}(Heat\ Advection\ (+), Heat\ Conduction(+), Heat\ Consumed(-))\right) \qquad \text{Eq. 2}$$

The utilizable heat (*Heat Utilizable*) for thermal use (either heating or cooling) can be displayed in the unit energy available per year (J/year) or thermal work available per year (Wh/year). It can be calculated for a particular land property by calculating the effective volume of the aquifer below the property or be displayed in terms of a specific value (Heat available per unit of area, e.g. MWh/ha).

The energy balance considers the following parts:

- Volumetric energy content of the aquifer (*Heat Aquifer*) taking into account the energy stored in the water filled matrix of the groundwater body with respect to the maximum allowed temperature change of the groundwater (e.g. 1 K).
- Advective heat supply (*Heat Advection*) based on the inflowing thermally undisturbed groundwater (In case of a stagnant groundwater body this term is equal to zero).
- Conductive heat supply (*Heat Conduction*) is provided by the heat exchange from the surface (major share) and the basis (minor share, terrestrial heat flow density). As the terrestrial heat flow density only provides a very low share of the energy recharge, the conductive heat supply is dominated by the surface temperature and by the distance between the topographic surface and the surface of the groundwater body. For deeper aquifers the conductive heat supply can be neglected.
- Finally, a crucial impact on the utilizable heat within an area is controlled by the already consumed heat (*Heat Consumed*) related to existing external thermal groundwater use or by the consumption at the investigated property itself. In case of absence of external users, this part of the balance is controlled by the annual energy balance of the thermal groundwater use planned. A balanced use (amount of annual heat extracted is equal to the amount of heat drained) means the open loop system is used both for heating and cooling at the same amount of energy. If this is the case, this term becomes zero and the total amount of utilizable energy at a given property or unit of area raises. However this term was not included in any of the investigated approaches.

The relation between thermal work or energy available at a certain area unit and the thermal capacity is given by sum of thermal power at a defined operation period (e.g. hour):

$$W = \sum_t P_{\pm}(t) \qquad \text{Eq.3}$$

For a defined period of time, for example one year, the energy consumed (Joule or Wh/a) equals Eq. 3. In turn, the term Heat Utilizable in Eq. 2 divided by the expected operational period (τ) leads to the average thermal capacity (P) to be expected at an investigated location

Taking into account the annual balance of the energy already consumed, offers the opportunity to raise awareness of users for a sustainable utilization of open loop systems and allows to energetically manage the use of groundwater bodies.

The subsequent sketch in Figure 4 shows the relation between thermal capacity and energy.

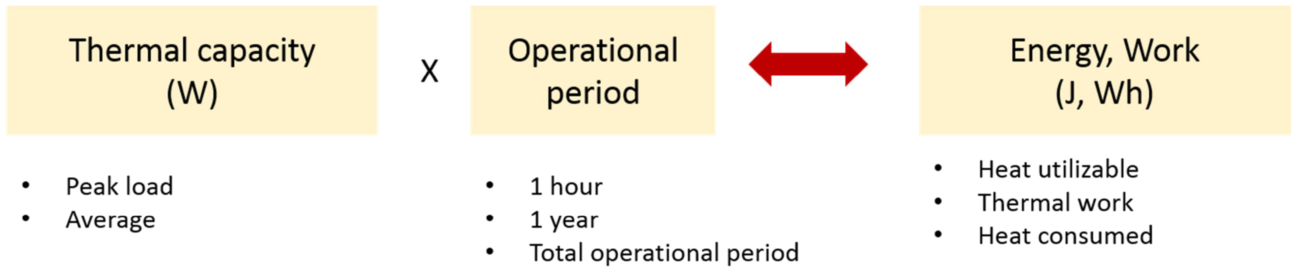

Figure 4: Relation between thermal capacity and heat.

Hydraulic productivity

The hydraulic productivity delimitates the yield or pumping rate (e.g. l/s) of a specific well at a certain location. It is not depending on the energy available at the location, but on the hydraulic attributes of the aquifer like effective thickness and the hydraulic conductivity. For simplification reasons the geometry of the well is neglected. In simple approaches, the hydraulic productivity is set equal to the natural recharge or total yield of a groundwater body. The hydraulic productivity can be defined for peak load (maximum pumping rate) or average pumping rates at a given operational period (daily or annual sum).

Thermal productivity

The thermal productivity reflects the available thermal content of a groundwater body in terms of a temperature shift between a production and injection well, as indicated in Eq. 1. The thermal productivity can be delimitated by the physical properties of groundwater (freezing) or by legal constraints in order to avoid an excess heating of the aquifer in terms of a maximum allowed inlet temperature (e.g. 20°C in Austria) or a maximum allowed temperature shift between the injection well and the current temperature of the aquifer (=temperature of production well). The thermal capacity can also be defined for peak load (at a defined number of hours per year) or at other defined operational period (e.g. daily or annual average).

Summary

Table 4 shows the chosen approaches for geothermal potential of the screened projects. The hydraulic productivity has been taken into account in all of the projects, whereas the energy content is only considered in two of them. Hydrogeological units are a part of the hydraulic productivity and were used in the Slovenian project (Rep. ID 17). However, in that project no quantitative estimation of the hydraulic productivity was conducted.

Table 4: Approaches of selected projects for geothermal resources

Project	Hydraulic productivity	Thermal productivity	Thermal capacity	Energy content
Shallow geothermal potential of Vienna (Rep. ID7)	x	x	x	x

IIOG-S - Assessment of shallow geothermal potential for Salzburg (Rep. ID22)	x	x	x	
Geothermal resources in Slovenia (Rep. ID17)	(x)			
Screening tool for open-loop ground source hat pump schemes - England and Wales (Rep. ID16)	x			
Geothermal Resource Map of Ireland (Rep. ID62 and ID63)	x			
Mapping the low enthalpy geothermal potential of shallow Quaternary aquifers - Finland (Rep. ID1)	x	x	x	
Potential map for an integrative management of open loop systems in Aspern Nord - Vienna (Rep. ID65)	x	x	x	x

Overview of existing workflows and parameters needed

General workflow schemes

Based on the screened projects, the general workflow of estimating resources associated to open loop systems consists of the following main steps:

i. Identification and outlining of aquifers suitable for the application of open loop systems

ii. Estimation of resources

iii. Data assembly, visualization and estimation of uncertainties

As the project IOG-S (ID22), performed for the state of Salzburg in Austria, represents a quite sophisticated approach for resource mapping at a regional scale, it has been chosen as benchmark for a general comparison of the applied workflows in the studies screened for this report. The general workflow of IIOG-S is shown in Figure 5.

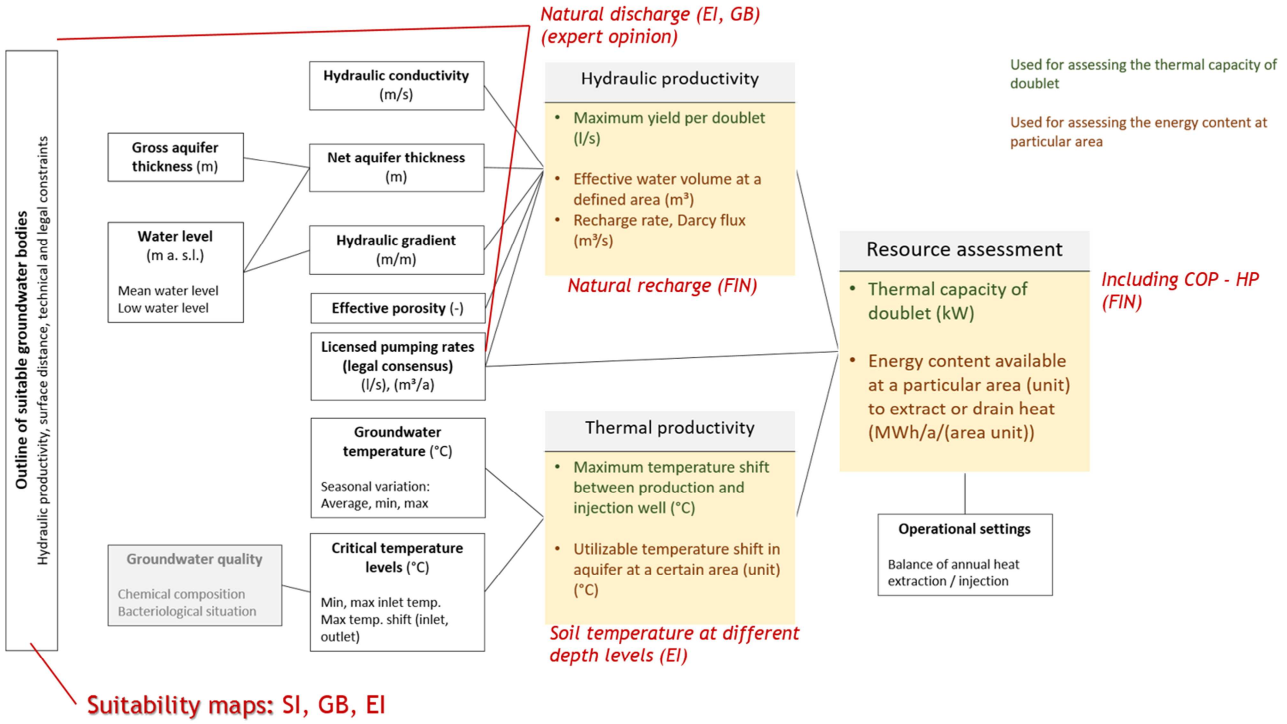

Figure 5: General workflow scheme applied in the project IIOG-S (Rep. ID22) to estimate the resources associated to open loop systems at a regional scale. ***The IOG-S workflow is compared to other approaches described in the screened literature.***

In general, all approaches screened in the literature study more or less follow the workflow presented in Figure 5. The basis of all resource studies was represented by an outline of aquifers suitable for applying open loop systems (listed above as step i.). While the calculation of the hydraulic productivity (part of step ii. as listed above) was performed based on several hydraulic characteristics in the project IIOG-S, the Finnish study (Rep. ID1) set the hydraulic productivity equal to the total natural regional discharge of the investigated shallow aquifers, which have been taken from a national hydrogeological database (Hertta database). The developed "Screening tool for open-loop ground source heat pump schemes" in England and Wales (Rep. ID16) attributed known aquifers, divided into hydrostratigraphic units, into yield classes based on expert opinions. The study on the shallow geothermal potential maps of Vienna – Austria (Rep. ID7) followed a similar approach as developed for IIOG-S performed by the same research team (Geological Survey of Austria). It has to be mentioned, that the approach applied in the study for the city of Vienna (WC-31, Rep. ID7) was further developed in the project IIOG-S (Rep. ID22).

Concerning the estimation of the thermal productivity (part of main working step ii.) the temperature shift extractable between the production and the injection well was calculated based on groundwater observation wells in the Austrian studies IIOG-S (Rep. ID22) and W-31 (Rep. ID7). The Finnish study (Rep. ID1) assumed a constant temperature shift irrespective of the natural groundwater temperature variation, although the project team was aware of low groundwater temperatures to be expected in Finland (maximum groundwater temperature in the south of the country approx. 6,6°C).

The installable thermal capacity was finally calculated at the Austrian, regional scale, resource studies (Rep. ID7 and Rep. ID22) and at the Finnish study (Rep. ID) based on the Eq. 1 presented in chapter 0. All other studies did not reveal quantified calculation of the installable thermal capacity. The Irish geothermal map (Rep. ID62) does not include the groundwater temperature in the suitability classification, due to low seasonal and regional groundwater temperature variations.

The energy available at a specific area was only calculated at a local scale study in the city of Vienna (Rep. ID 65) based on analytic calculations. The Finnish study (Rep. ID1) approached the area specific heat content available by dividing the installable thermal capacity by the size of the identified suitable aquifer (kW/ha).

Most of studies screened either base on qualitative approaches or simplified resource estimation based on analytical calculations. Numerical modelling has only been applied in one study at the city of Vienna (Rep. ID65).

Quantitative data assembling (part of main working step iii., presented in the beginning of this chapter) has only been performed in the Austrian and Finnish studies. In these studies, available resource data, gained from working step ii., have been statistically assembled to vector based aquifer units. Concerning publishing and visualization of resources, all studies except the Finnish one (Rep. ID1) only display discrete classes instead of specific values. The studies screened for Ireland and the UK published discrete hydraulic productivities based on expert opinions only. Finally, it has to be mentioned, that none of the screened studies performed a comprehensive quantitative estimation of uncertainties.

More information on the main working steps can also be found in the subsequent chapters 0 to 0 of this report. The next chapter will describe the input parameters needed to estimate resources related to the use of open loop systems.

Input parameter needed

The general workflow scheme, described in Figure 5 is linked to different data sources needed in order to map resources of open loop systems. The subsequent Table 5 shows the link between input parameters and main data sources identified in the screened project reports:

*Table 5: Overview of relevant data sources of input parameters for resource assessment of open loop systems. **Light colored data sources have not been considered in the screened projects. Blue colored cells indicate aimed output parameters, which may directly be derived from input data without combination of different input parameters.***

Ref.	Input parameter	Relevant data sources
1	**Outline of suitable groundwater bodies**	• Existing hydrogeological or geological maps • Hydrogeological mapping
2	**Gross aquifer thickness**	• Geological borehole profiles: lithology, stratigraphy • Geological cross-sections
3	**Water level**	• Existing groundwater maps for a given observation period

		• Water level time series in observation wells
4	**Groundwater quality**	• Datasets related to the EU Water Framework Directive for quality monitoring of groundwater bodies (chemistry) • Analyses of water samples gained from wells (microbiology)
5	**Hydraulic conductivity**	• Processed pumping (production-) tests in wells • Modeled, based on grain size distribution and lithological classification
6	**Net aquifer thickness**	• Existing thickness maps and 3D models • Combined from Ref. 2 and 3
7	**Hydraulic gradient**	• Existing hydraulic maps • Calculated from Ref. 3
8	**Effective porosity**	• Processed pumping (production-) tests in wells • Estimation based on lithological build-up
9	**Licensed pumping rates (legal concensus)**	• Databases of authorities (in some countries avalailable) • Archives of authorities, if applicable due to data privacy rules
10	**Groundwater temperature**	• Temperature monitoring in observation wells • Climatic maps (surface air or soil temperature)
11	**Critical temperature levels**	• Legal acts or guidelines describing state of art • Derived from Ref. 4
12	**Operational settings**	• Archives of authorities if applicable due to data privacy rules • Databases of authorities
13	**Recharge rate**	• Hydrogeological maps

Ref. 1 and 2 from Table 5 have been derived in the screened studies from existing maps and literature sources. In many projects screened, hydraulic input data needed to derive Ref. 3, 6 and 7 are not fully covered by hydraulic maps or models. Instead, they have been derived from single observation wells investigating a particular time period by interpolation or modelling. To avoid data filtering effects, the produced hydraulic maps never referred to averaged hydraulic productivities derived from single observation wells but referred to reference day observations.

Relevant reservoir parameters referring to the aquifer (Ref. 5 and 8) were hardly available in the projects screened. In some cases, the hydraulic conductivity (Ref. 5) was roughly averaged based on results from pumping tests by correlating them to lithological units. For the project in Vienna (Rep. ID7), the poor data background of available processed pumping tests was amended by the derived hydraulic conductivity from available grain size distribution data. The effective porosity (Ref. 8) was roughly estimated and assumed homogenous within an aquifer in most projects screened.

Groundwater temperature data (Ref. 10) were available in terms of recorded time series at individual observation wells only in the project screened (e.g. Vienna and Salzburg). Groundwater temperature maps therefore represented aimed outputs of resource assessment studies. In the Finnish study (Rep. ID1), the available groundwater temperature data have not been considered at all. Instead a constant temperature shift of 3K was assumed for the whole country.

Operational data (Ref. 9 and 12) were only available in a few projects screened (Vienna Rep. ID7 and Salzburg Rep. ID22) as these data are subject to data privacy restrictions in many countries or are not available at the relevant permitting authority in terms of digital datasets. In that cases rough estimations concerning operational parameters of already existing uses (e.g. temperature difference at well doublets) had to be performed (e.g. Vienna Rep. ID7). In contrast, critical temperature levels, which were considered in resource mapping (Ref. 11), could be directly taken form guidelines and legal acts, if they existed.

The input parameter groundwater quality (Ref. 4) was not directly used for the assessment of resources, but instead fed into conflict of use and environmental risk mapping. However, the quality of groundwater bodies with respect to microbiological characteristics is hardly investigated in Europe yet. In contrast, the chemical composition including anthropogenic contamination is well observed in most EU countries due to requirements of the EU Water Framework Directive (EUROPEAN PARLIAMENT & COUNCIL, 2000).

Geological and hydrogeological maps were used in the Slovenian project (Rep. ID17) to provide a rough overview of the recharge rate (Ref. 13) at a certain location. At the screened projects from the UK (Rep. ID14, 14 and 16) the recharge rate was derived from expert opinions. In the Finnish study (Rep. ID1), the average aquifer recharge was taken from a national database and set equal to the discharge by dividing through the size of the area of the aquifer.

Step 1: Delimitation of suitable aquifers

All projects screened outlined areas suitable for the application of shallow geothermal use in a first step. The definition of areas considered the following criteria:

Hydrogeology

- Aquifers showing a sufficient yield or natural recharge (all projects screened)
- Aquifers or zones within an aquifer not reserved for drinking water supply (IIOG-S, Rep. ID22).
- Uppermost groundwater body showing a mostly phreatic behaviour (Austrian projects Rep. ID7 and Rep. ID22).
- Aquifers with a maximum overburden thickness (Rep. ID16 and Rep. ID22)

A minimum groundwater temperature was not considered as a pre-filtering criteria for selecting areas suitable for the use of open loop systems at the project screened. However, the Austrian project SC27 (Rep. ID22) later excluded areas with minimum groundwater temperatures not suitable for the use of open loop systems.

Non geoscientific aspects

- Areas dedicated to permanent settlements (IIOG-S, Rep. ID22)
- Urban- or industrial land use (Finnish project, Rep. ID1)

The outline of hydrostratigraphic units suitable for open loop systems mainly based on existing hydrogeological and geological maps. These input data sources were widely available in all screened projects. In fact, the more important constraint was given by a suitable geographical scale of the available input maps and cross sections referring to the aimed geographical resolution of the resource assessment studies. The scale of the input maps also determines the minimum scale of the produced resource maps. The screened projects indicate, that the used geological input maps are usually available at regional scales (e.g. 1:200.000, q.v. England and Wales project - Rep. ID16), although in the project IIOG-S (Rep. ID22) input maps at different scales from 1:500.000 to 1:50.000 were used to compile hydrostratigraphic units. The scale of the maps used for the Irish project (Rep. ID 62) were 1:100.000. The smallest project area investigated was given by the city of Vienna (Rep. ID7) at the scale of input maps between 1:25.000 and 1:50.000.

In most of the projects screened, the information given at the available input maps and cross-sections were in a next step reviewed and interpreted by experts to derive areas within an aquifer suitable for the application of open loop systems considering the above listed hydrogeological criteria.

In the project "Geothermal resources in Slovenia" (Rep. ID17) the whole country was divided into five qualitative categories of suitability for different systems of shallow geothermal use based on the hydrogeological and geological considerations. The classes distinguished between areas suitable for open loop, closed loop and larger borehole heat exchanger fields.

The method developed for the "Screening tool for open-loop ground source heat pump schemes" in England and Wales (Rep. ID16) identified suitable hydrostratigraphic units with respect to aquifer yields and the depth of the groundwater surface. A bedrock aquifer potential layer was derived from the 1:250.000 map of geological bedrock formations. Each unit was attributed toward its potential of providing < 1 l/s (no suitable aquifer), 1 – 6 l/s (moderate aquifer) and > 6 l/s (good aquifer), given that the depth to the source is ≤ 300m. "Source" refers to the uppermost aquifer present at any location. Furthermore, information about groundwater chemistry, existing maximum licensed abstraction (m^3/d) and protected areas is provided for any given location.

The "Geothermal Resource Map of Ireland" (Rep. ID62) was also based on hydrogeological maps and the expected range of hydraulic productivity (yield, based on the unit m^3/d). All aquifers are divided into 11 categories according to their geological structure, their groundwater flow regime, their groundwater temperature variability, and their typical yields that can be expected based on known well yields around the country.

In the screened Austrian projects (Rep. ID7 and ID22), the identification of suitable aquifers mainly based on existing hydrogeological and geological maps. At the project IIOG-S (Rep. ID22), the depth level of the groundwater surface and priority areas for drinking water supply as well as areas with significant risk of over pressured groundwater bodies have also been taken into account for determining the outlines of suitable hydrostratigraphic units. For that reason, a review of external experts was applied for finalizing the suitability map.

For creating the geothermal potential map of Vienna (Rep. ID7) the hydrogeological map (1:25 000) was divided into 14 sub-areas, identified by geological and hydrogeological attributes. These attributes reflected the general lithostratigraphic description of the uppermost approximately 50 meters of the subsurface (synthesis of quaternary and / or uppermost sections of the Miocene sediments) and were used for potential maps of both, closed- and open loop systems.

At all projects screened, the produced suitability layers for the application of open loop systems were represented by vector datasets. Raster sets have not been produced due to the lack of high spatial density input data.

Step 2: Estimation of available resource

In this chapter, the different approaches and workflows applied in the screened projects for estimating resources associated to the use of open loop systems will be presented and discussed. The different terms describing resources have been presented in chapter 0 of this report. The link between input data and resources is also shown in Figure 3. The description of workflows applied will use the methods used in the project IIOG-S (Rep. ID22) as benchmark.

Hydraulic productivity and legal stock

As described in chapter 0, the hydraulic productivity describes the maximum amount of groundwater withdrawn in a defined period (peak load, hourly, daily or annual basis). In addition, the legal stock describes pumping rates already permitted by licensing authorities for open loop systems. Equal to the hydraulic productivity, it delimitates the maximum allowed amount of pumped groundwater in a certain period. Both terms have been introduced in the project IIOG-S (Rep. ID22).

In the project for creating potential maps for the city of Vienna (Rep. ID7), the hydraulic productivity was set equal to a maximum pumping rate at peak load (Q_{max}). The maximum discharge permitted for each well doublet was calculated using a variation of Thiem's approach (1906), which depends on the hydraulic conductivity (kf), the thickness of groundwater at low (m_{NGW}) and average water level (m_{MGW}).

$$Q_{max} = kf \cdot (m_{NGW} - 1) \cdot m_{MGW} \quad \text{Eq. 4}$$

The maximum drawdown permitted was set to m_{NGW} – 1 meter to allow a minimum net aquifer thickness in the well of 1 meter. However, the chosen threshold of the maximum drawdown is rather arbitrary and the thickness of groundwater at low water level is not always available. Furthermore, the hydraulic range is not taken into account in the equation. Therefore this equation has not been used again in other studies performed in Austria and is considered unsuitable to calculate the geothermal resources accurately. The effective thickness at different hydraulic conditions (average- and low water table) were derived from an available structural map of the aquifer (raster dataset covering the most important aquifer in Vienna) and hydraulic maps. In those parts of Vienna, where no maps were available, the effective thickness was calculated on the basis of single wells for which the needed input parameters were available. The hydraulic conductivity was derived from single pumping tests and, complementary, modelled based on grain size distribution data.

A more sophisticated and accurate method to determine the hydraulic productivity (see also Eq. 5) was developed at the project IIOG-S (Rep. ID22). This modification of Thiem's approach estimated the maximum pumping rate (Q_{max}) for a specific well based on the average water level (MGW) and the maximum drawdown of 1/3 of the effective groundwater thickness at average water level. The equation also includes the hydraulic radius (R), which is calculated based on Eq. For simplification reasons, the radius of the well (r_{well}) was set to 1m to be independent from the geometry of the well. However, the influence of the well design is rather small.

$$Q_{max} = \pi \cdot kf \cdot \frac{5 \cdot m_{MGW}^2}{9 \cdot lnR}$$ Eq. 5

$$R = 3000 \cdot \frac{M_{MGW}}{3} \cdot \sqrt{kf}$$ Eq. 6

At the IIOG-S project, the hydraulic productivity was calculated on basis of single wells for most aquifers suitable for the use of open loop systems in Salzburg. Only for some hydrostratigraphic units information about the geometry and the hydraulic conditions were available in terms of maps. Unfortunately, the sensitive parameter hydraulic conductivity had to be derived from only a few pumping tests.

At the project IIOG-S, legal stocks published at a publically available register (so called "Wasserbuch") have been used to validate the calculated hydraulic productivities and to fill data gaps. For validating the calculated hydraulic productivity the following principle rule was checked:

$$Q_{leg} \leq Q_{max}$$ Eq. 7

In the previous project Transenergy, not screened for this report, the legal stock was also called "legal potential", referring to deep geothermal use. The calculated maximum hydraulic potential [l/s] must not be smaller than the maximum pumping rate allowed by the authorities (legal stock at the unit [l/s]).

In the local scale potential and planning study for the Seestadt Aspern in the city of Vienna (Rep. ID65) the hydraulic productivity was estimated in terms of an average pumping rate for estimating the energy content available at specific construction sites. The average pumping rate is equal to the annual water use by multiplying it with the operational hours per year. For this purpose a simplified calculation for the maximum pumping rate of a well doublet was derived from OEWAV guideline RB 207 (Eq. 8). The parameters feeding into the discharge are represented by the hydraulic gradient at the groundwater body (i), the hydraulic conductivity (kf), the effective thickness (m) and the maximum distance between the two wells of a doublet (a), at a given area (A), which was simplified to a square shape.

$$Q_{mean} = \frac{a \cdot i \cdot kf \cdot m}{0.6}, \; a = \sqrt{2 \cdot A}$$ Eq. 8

The other projects screened used information from existing wells, databases or hydrogeological maps to derive the hydraulic productivity instead of calculating it based on analytical approximations.

The hydraulic productivity of the Finnish aquifers (Rep. ID1) was calculated by calculating the share of urban and industrial land-use of the aquifer's recharge, which was taken from a publically accessible database (Hertta Database 2012) for hydrogeological information. The surface related land-use filter was taken from the land cover database (CORINE 2006 database) using Esri ArcGIS for geostatistical calculations. The resulting areas joint by Hertta and CORINE were afterwards exported to a new groundwater energy database. Missing recharge values in the Hertta Database for a particular aquifer were complemented based on expert interviews or on legal stocks of existing wells.

In the projects of England and Wales (Rep. ID16), and Ireland (Rep. ID62) the hydraulic productivity was interpreted from a bedrock aquifer potential layer, which was derived from a 1:250 000 geological map of bedrock formations. Aquifers in overlaying sediments were not available. Each unit was attributed according to its potential of providing a pumping rate of <1 l/s, 1-6 l/s and >6 l/s. This classification mainly founds on expert's knowledge without the performance of any calculations. For Ireland, the range of expected pumping rate were assigned to 11 hydrostratigraphic units, based on legal stocks, tested well discharges and observed natural spring discharges in Ireland. These information was taken from the well and spring database of the Geological Survey of Ireland.

Only a qualitative description of the hydraulic productivity was conducted at the project in Slovenia (Rep. ID17). No additional data about aquifers were gathered and the identified hydrogeological units were assigned to specific suitability classes.

To summarize, only the screened studies executed in Austria tried to estimate the hydraulic productivity based on simplified analytical calculations taking account the geometry and the hydraulic attributes of groundwater bodies. In contrast to the geometry and the water table, which could be derived from wells, the parameter hydraulic conductivity, which represents the most sensitive parameter at calculating the hydraulic productivity, was estimated or averaged based on a few observation points.

The studies performed in Finland and Ireland used hydraulic data available in existing databases. All mentioned studies also considered licensed pumping rates (legal stock) for filling data gaps or for validation reasons. The potential study in the UK (Rep. ID16) derived the hydraulic productivity from expert opinion only. The estimation of the hydraulic productivity based on analytical calculations allows a more precise regionalization of resources. However, for that approach, information about the geometry of the aquifer, the water table and hydraulic parameters have to be available at least for single wells. The legal stock gives good estimations on the hydraulic productivity, although it has to be considered, that this parameter always represents the combination of the user demand on energy or water and the existing hydraulic productivity. This fact leads to Eq. 7.

Thermal productivity

The term thermal conductivity describes the available thermal content in a groundwater body, expressed by the temperature shift (ΔT) between the production well and the injection well, which is available for both, heat extraction and heat injection (see also chapter 0 or Eq. 1). The thermal productivity is limited by technical (freezing point of water) and legal constraints (maximum temperature shift or inlet temperature).

In the Finnish study (Rep. ID1), the thermal productivity was set to a uniform number of ΔT=3°C irrespective of the average groundwater temperature in different regions of the country.

The screened Austrian studies for Vienna and Salzburg (Rep. ID7, ID22) calculated the thermal productivity for different hydrostratigraphic units based on groundwater observation wells. For that purpose, time series of the previous 10 years have been statistically analysed. The 10th as well as the 90th percentile were chosen to represent the expected minimum and maximum groundwater temperature at each investigated well to filter out aberrations. The statistical key values of each well have later been summarized to hydrostratigraphic units based on the same approach. By doing so, a rather conservative approach has been chosen to estimate the minimum and maximum aquifer temperature. In a last step, these extreme values have been combined to the threshold temperature values (minimum inlet temperature: 5°C, maximum inlet temperature: 20°C, maximum temperature shift: 5°C) to calculate the available minimum temperature shift at the least suitable point of the season. In the project IIOG-S (Rep. ID22) it was also tried to apply a seasonal filter (differing between heating and cooling period). But as detailed information on the climatic seasons were missing for Salzburg this approach has been dismissed.

In the local scale study at "Seestadt Aspern", Vienna (Rep. ID65), the thermal capacity was further differentiated into peak load (maximum on an hourly basis) and average productivities on a daily, weekly and annual basis. By doing so, the energy content available at a specific area can also be taken into consideration.

All other studies screened did not account for the thermal productivity.

Thermal capacity

The thermal capacity was estimated only in the Finnish (Rep. ID1) and Austrian projects (Rep. ID7, ID22). In all projects mentioned, the thermal capacity was calculated based on Eq. 1 for peak load. The temperature dependency of the volumetric heat capacity as well as the influence of mineral contents of the groundwater was not accounted for in all projects screened.

Eq. 1 only takes the share of the heat produced form the aquifer into account while the exergetic input by the heat-pump is neglected. In addition, for the Finnish project, the amount of heating power that can be delivered to heat distribution systems by heat-pumps (P_{tot}) was derived from the thermal capacity of the aquifers, given that 100% of the amount of heat is exploitable, no heat loss occurs in the evaporator of the heat exchanger and heat from the compressor is delivered efficiently. A value of 3.5 based on literature was used for coefficient of performance (COP). Based on Eq.1, the total amount of heat produced is given by:

$$P_{tot} = Q \cdot \Delta T \cdot \frac{cp}{1-\frac{1}{COP}} \qquad \text{Eq. 9}$$

Energy content available

In addition to the geothermal resource maps for the entire city of Vienna (Rep. ID7) showing the thermal capacity, the energy in place was estimated on a local scale for the urban development area “Seestadt Aspern” (Rep. ID65). Two different workflows were developed, one for unbalanced use (only heating or cooling) and for an annually balanced energy use. In general, the chosen approaches followed Eq. 2 (see chapter 0), but did not consider all terms stated in that equation. The energy in any given area was calculated to highlight the differences in efficiency between unbalanced and balanced annual heat use. In this project, the energy in any given area was represented by the annual thermal work (W) to extract heat from or to drain into the aquifer (MWh/a). The calculation itself was performed with scalar balance not taking local heterogeneities within the investigated area into account. The maximum annual work for a balanced use ($P_{area\_balanced}$ [MWh/a]), is described by:

$$P_{area\_balanced} = Q_{mean} \cdot \Delta T \cdot t_{0.5} \cdot \langle cp \cdot \rho \rangle_w \qquad \text{Eq. 10}$$

The hydraulic productivity Q_{mean} is described in Eq. 8. The result for $t_{0.5}$ = 4380h (total hours of half a year) represents the annual energy content of a given area for heating and cooling.

For a sustainable but unbalanced use, either heating or cooling, ($P_{area\_unbalanced}$ [MWh]) less energy is available, due to missing thermal regeneration of the aquifer. The allowed shift in temperature (ΔT) of the aquifer below a real estate (A·m) is set to 1K and the volumetric heat capacity of the aquifer was set to 2.5 MJ/(m^3·K) in Eq. 11.

$$P_{area\_unbalanced} = A \cdot m \cdot \Delta T \cdot \langle cp \cdot \rho \rangle_a \qquad \text{Eq. 11}$$

Step 3: Mapping, estimation of uncertainties and visualization

In general, mapping of estimated resources can be achieved by raster interpolation (gridding) and statistically data assembling for defined hydrostratigraphic units. Gridding can be performed in case of a sufficiently high spatial density of available input data. Depending on the interpolation algorithm applied, the needed spatial density is related to the cell size applied. However, in order to avoid gridding based artefacts, the average distance of nodes should not exceed 5 to 10 times the desired cell size. In almost all studies screened, this criteria was not fulfilled. In addition, the basic layer all studies screened, was given by defined hydrostratigraphic units suitable for open loops systems, represented in terms of vector data sets. For that reason, the information available based on single datum points (wells, springs) were summarized by averaging or calculating extreme values for these hydrostratigraphic units. In the Irish and UK projects, data gaps were also filled by expert opinions (educated guesses). In most cases except for the Finnish project (Rep. ID1) the data have been exported in terms of vector datasets. The Finnish project finally created raster data sets for intersecting the geoscientific attributes with Corinne landsat raster.

The estimation of uncertainties related to the described resources for open loop systems either has not been displayed in the produced output maps or has not been estimated at all. The Finnish project performed some rough error analysis in the final report (Rep. ID1) without giving a regionalized analyses of uncertainties. However, most of the screened projects only delivered a disclaimer to the produced output data-sets saying that they do not replace a detailed feasibility study. Other displayed disclaimer statements are:

- A permission for an open loop system is not automatically guaranteed for sites in favourable or highly suitable areas.
- The screening tools are not updated. Not one single project states, that updated versions are or will be available in the future.
- The resource maps are limited to schemes of a certain capacity (e.g. non-domestic with >100 kW in England and Wales). With the exception of Ireland (Rep. ID62), where two maps were created for small and large scale installations of open loop systems.
- Mostly, not all aquifers of one area are covered. Only bedrock aquifers are included in the British project, therefore possible resources in superficial deposits overlying the bedrock are neglected. The opposite is the case for the Austrian projects, which focus on the superficial deposits.
- The sustainability of planned open loop systems is not considered. A possible thermal interference between existing and new applications is neglected. This may be an issue in areas where a large number of schemes has already been installed.
- The reduction in aquifer productivity near the outcrop boundaries due to decreasing thickness of the aquifer is not considered. Hence, there is a higher degree of uncertainty regarding the predicted aquifer potential near these boundaries.
- The tool does not consider the suitability of the aquifer for reinjecting water. This information has to be obtained from site-specific investigations or field tests.

In the project IIOG-S (Rep. ID22), the thermal capacity was only calculated for those hydrostratigraphic units, at which all input data were available. If this was not the case, only productivities (thermal or hydraulic) were shown or the unit was marked as no data available. This was done to avoid to implement educated guesses in output data-layers.

Finally, the subsequent Table 6 compares the data classes applied for describing resources in the screened projects:

Furthermore, qualitative maps have also been applied to describe resources. Qualitative maps represent the interpretation of geoscientific settings with respect to current policies. In many cases these maps are reduced to so called traffic light layers (go, no-go, on-hold for further investigations) or intend to support or sharpen the decisions of actors (authorities, investors) in terms of so called suitability layers (shown in Table 6). Some of the screened projects provide interpreted maps instead of or additional to geoscientific (quantitative) maps. The interpreted maps show the suitability of shallow geothermal applications. The background of a suitability classification was rarely documented. Information about the parameters and how they are implemented into the classification is often missing.

Table 6: Output parameter indicating the geothermal potential for open loop systems of screened projects and suitability classes displayed on the potential maps.

Project	Parameter indicating geothermal potential	Suitability classes
Shallow geothermal potential of Vienna (Rep. ID7)	Heating power (W)	1: Open loop systems not recommended < 1 kW 2: Small sized applications after evaluation of local situation possible 1-<5 kW 3: Medium sized applications after evaluation of local situation possible 5-<20 kW 4: Large sized applications and local grids after evaluation of local situation possible >20 kW
IIOG-S - Assessment of shallow geothermal potential for Salzburg (Rep. ID22)	Thermal productivity (°C), hydraulic productivity (l/s), thermal capacity (kW)	Thermal productivity: <2.5°C, 2.5-5°C, >5°C, no potential available, no data. Hydraulic productivity: <10 l/s, 10-20 l/s, >20 l/s, no data. Thermal capacity: <10 l/s, 10-50 l/s, >50 l/s, no data.
Geothermal resources in Slovenia (Rep. ID17)	Hydrostratigraphic units	1: Most commonly vertical collectors 2: Most commonly groundwater heat pumps 3: Most commonly vertical/horizontal collectors 4: Often groundwater heat pumps 5: Most commonly unsuitable for larger BHE fields
Screening tool for open-loop ground source hat pump schemes - England and Wales (Rep. ID16)	Aquifer potential discharge (l/s)	1: No suitable aquifer <1 l/s 2: Moderate aquifer 1-6 l/s 3: Good aquifer >6 l/s
Geothermal Resource Map of Ireland (Rep. ID62 and ID63)	Hydrostratigraphic units	1: Generally unsuitable (site assessment required) 2: Possibly unsuitable (site assessment required) 3: Probably suitable (unless proved otherwise/site assessment required) 4: Suitable 5: Highly suitable
Mapping the low enthalpy geothermal potential of shallow Quaternary aquifers - Finland (Rep. ID1)	Heating power (W)	1: 1-<100 kW 2: 100-<200 kW 3: 200-<500 kW 4: >500 kW
Potential map for an integrative management of open loop systems in Aspern Nord - Vienna (Rep. ID65)	Energy content available (MWh/yr)	No classes, instead specific values for each construction site

The Irish project (Rep. ID62) sets an example for a rather complex classification system. Two suitability maps are provided for open loop systems for domestic and smaller commercial use and for larger commercial and industrial processes. The web based information system lacks a clear description of the differences between the two systems (domestic and smaller commercial use vs. larger commercial and industrial processes) and between the suitability classes. Both Irish maps contain five classes of suitability: “Highly suitable” – “Suitable” – “Probably suitable (unless proved otherwise/Site assessment required)” - “Possibly unsuitable (site assessment required)” – “Generally unsuitable (site assessment required)”.

A description of the methods and approaches of the IOG system for Bavaria is unfortunately not available. Therefore only the visualisation of the map can be discussed here. The suitability map includes three suitability classes for open loop systems at a particular site: “Installation is presumably possible” – “Installation is subject to case-by-case decision conducted by an expert” – “Installation is presumably not possible”. A description of the parameters used for the classification is missing.

Summary and conclusions

The investigated publications show various workflows and different output parameters to determine and visualize the geothermal resources for open loop systems. The workflows of the mapping methods depend on the aims of the projects and the data availability. It is important to distinguish between maps providing only geoscientific information and policy maps, which provide interpreted geoscientific data and additional input from policy makers.

The literature study revealed that only few studies (Austria and Finland) tried to quantify resources related to open loop systems based on numeric input data. In the next chapter, the applied workflows are summarized and evaluated.

Summary of applied workflows

The most comprehensive workflows for quantifying resources for open loop systems have been applied in the Austrian studies (especially Rep. ID22 and ID65). The study IIOG-S (Rep. ID22) also introduced the terms “hydraulic productivity”, “legal stock” (formally called “legal potential”, initially introduced in the Transenergy project) and “thermal productivity”. Although not explicitly called like that, these parameters have been considered in the Finnish, UK and Irish projects.

In a first crucial working step, all screened projects have defined hydrostratigraphic units suitable for the use of open loops systems. This dataset, mostly represented in terms of a GIS vector dataset, has been later used to create suitability maps (e.g. traffic light maps). Both, the Finnish project (Rep. ID22) and the Salzburg project (Rep. ID22) have intersected the outlines of suitable hydrostratigraphic units with surface infrastructure filters. In case of the Finnish project, the surface filter was represented by urban or industrial land use, based on Corinne landsat data. The Salzburg project instead was only calculating resources for areas dedicated to permanent settlements. This dataset was available at the government of Salzburg.

If calculated, the thermal capacity was derived from Eq. 1 describing the share of heat extracted form or drained into the aquifer. The Finnish project, in addition, also accounted for the exergy share delivered by the heat-pump to derive the total amount of heat available for the user (see Eq. 8).

In the detailed study for the urban development area "Seestadt Aspern" in the city of Vienna, also the available heat stored in the aquifer is calculated based on scalar heat balancing.

Conclusions

According to the investigated approaches the most difficult resource to determine is the discharge (hydraulic productivity). In that context, the most sensitive and at the same time least known parameter is represented by the hydraulic conductivity.

In addition, we want to conclude the following:

- Outlining hydrostratigraphic units suitable for the use of open loop systems is a crucial first step which has been executed in all projects screened. Hydrostratigraphic units have been either compiled or interpreted from existing geological and hydrogeological maps.
- The so called thermal and hydraulic productivities are important parameters to describe resources related to the use of open loop systems. Both productivities combined lead to the thermal capacity. As resources are related to a range of different input parameters (see also Figure 3), productivities may give important hints on the expectable resources in case not all needed input parameters to calculate the thermal capacity are available.
- The thermal capacity only describes the potential of use (in the unit of power) without taking into account the energy available, which depends on the operational hours of the open loop application. In the screened projects the thermal capacity was set equal to the maximum value at peak load.
- The most accurate description of shallow geothermal resources of groundwater is the energy content available in place, at it is accounting for the energy change in the aquifer from future and existing use. The heat available for open loop systems was estimated in one local scale study in the city of Vienna only. The calculation itself was performed by simple analytic balancing. It was later validated by numerical simulations.
- If the geothermal maps of GeoPLASMA-CE include suitability classes, there will be less classes and a better description of them, than in the Irish project (5 classes). A low ("less is more") and possibly even number of suitability classes helps to keep the maps easily understandable. Clear distinctions between suitability classes help to prevent misinterpretations of the potential maps by their users.
- In our opinion, it is better to derive quantified resources from sound data nodes (e.g. wells) than from subjective expert opinions to make the output datasets more transparent. In case of lacking input data, "no data" areas should be displayed to the end user.

Many geothermal maps, which were made available to the public via web-application, even lack rudimentary information about the methodology applied. However, target groups for using the produced outputs need background information in order to ensure a proper use of the maps. The following conclusions on visualization can be stated:

- A proper description of the suitability classes keep the maps easily understandable and help to prevent misinterpretations of the potential maps by their users

- Additional layers showing designated areas are a good way to include this information about the feasibility of open loop systems at particular sites.
- If the information on available resources is provided in many different data-layers, a so called location specific query, as applied in the project IIOG-S (Rep. ID22), allows a better transfer to the end user.

Outlook on harmonized workflows to be derived in GeoPLASMA-CE

The produced maps of the selected projects provide information on a different level of accuracy, which also depends on the aims of the project. However, it was realized, that all investigated approaches represent different stages of the following standardized workflow:

i. Definition and outlining of hydrostratigraphic unis suitable for open loop systems. Optionally applying further spatial filters related to surface land use (e.g. dedicated areas of settlement).

ii. Calculation of hydraulic productivity for hydrostratigraphic units at the level of individual wells or hydrostratigraphic units (depending on the quantity of available input data). Data gaps can be filled by licensed pumping rates of existing wells if available in the same stratigraphic units.

iii. Determination of thermal productivity according to groundwater temperature and legal requirements.

If only sparse input data available to calculate the productivities, the following methods can be applied instead of raster interpolation:

- Statistical summarizing for hydrostratigraphic units – in that case the amount of available input data and data ranges should be documented.
- Numerical modelling (e.g. hydraulic head), calibrated and validated by the available input data.

iv. Calculation of thermal capacity (combining thermal and hydraulic productivity) for hydrostratigraphic units.

v. In case of high density of use already exiting or estimated for the future in a hydrostratigraphic unit, the energy available in place should be calculated as well.

vi. Determination of the range of uncertainties as well as metadata-documentation with respect to the used input data.

vii. For data visualization and display we recommend to use a harmonized legend set-up in GeoPLASMA-CE. Furthermore, we intend to display only values discretized in space (raster datasets) and numerical values (value classes) to avoid any interpretation of data beyond the scale provided. The numerical discretization can for example set equal to the range of errors affected to the produced outputs.

References

63 national and international projects related to the main topics of GeoPLASMA-CE are stored as publications for further research in the database "knowledge repository" (Annex 2). These projects and publications were assessed regarding their applicability for work package 2 in GeoPLASMA-CE. The main focus of the research was the methodical approach to geological 3D-modelling, geothermal mapping for open and closed loop systems and land-use conflict mapping concerning geothermal potential mapping in regional and urban areas. Additionally, there were registered any other interlinks to technical work packages 1, 3 and 4 and some possible experiences for work package communication. All assessment sheets regarding open loop systems are added in Annex 1 for further information.

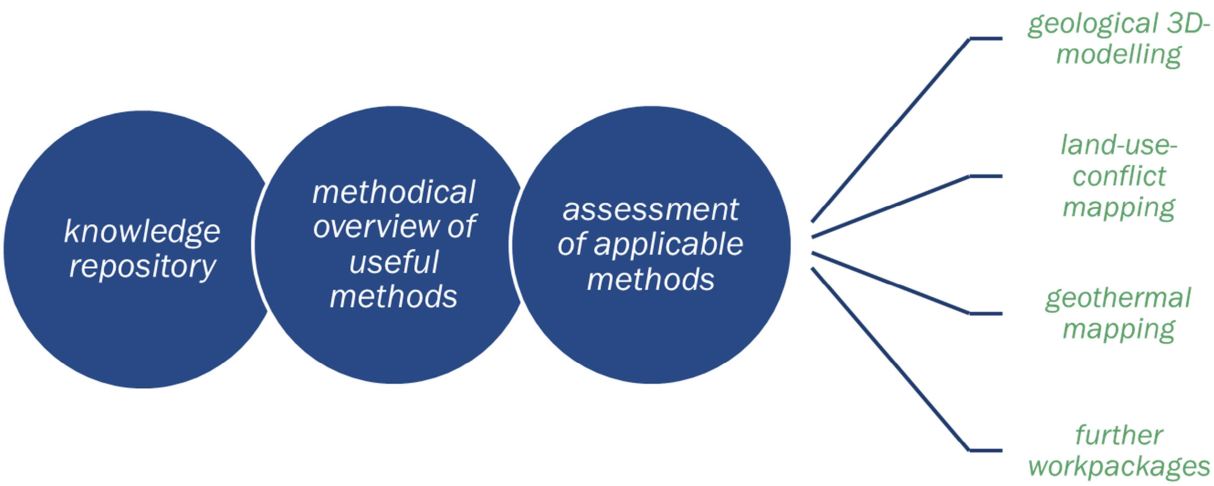

Figure 6: Methodical approach of the screening of literature performed in GeoPLASMA-CE

Besides the screening of specific reports, the following additional literature has been used:

EUROPEAN PARLIAMENT & COUNCIL; 2000; Directive 200/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy, (EU Water Framework Directive); OJ L 327.

OEWAV; 2009; OEWAV Regelblatt 207 Thermische Nutzung des Grundwassers und des Untergrunds – Heizen und Kühlen; Vienna.

THE HERTTA DATABASE; 2012; http://wwwp2.ymparisto.fi/scripts/hearts/welcome.asp ; Accessed 29 Dec 2011 and 23 Feb 2012

CORINE DATABASE; 2006; http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012

Table 7: knowledge repository methodical research

ID	literature type	Year/ last access date	Author	Title	Publisher, journal issue, vol., pp.	usefull for WP	linked to WP	Keyword1	Keyword2	Keyword3	web link (if available)
1	published	2014	Arola, T., Eskola, L., Hellen, J., Korkka-Niemi, K.	Mapping the low enthalpy geothermal potential of shallow Quaternary aquifers in Finland	Springer, Geothermal Energy, vol. 2, 9	TWP2		potential mapping	open-loop system		
2	published	2014	LfULG, PGI	Handbuch zur Erstellung von geothermischen Karten auf der Basis eines grenzübergreifenden 3D-Untergrundmodells; Podręcznik opracowywania map geotermicznych na bazie transgranicznego trójwymiarowego (3D) modelu podłoża	Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie;Państwowy Instytut Geologiczny - Państwowy Instytut Badawczy, Oddział Dolnośląski (PIG-PIB OD)	TWP2	TWP4	3D-modelling	potential mapping	use in regional areas	http://www.transgeotherm.eu/publikationen.html
3	published	2015	LfULG	TransGeoTherm - Erdwärmepotenzial in der Neiße-Region	Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie, Schriftenreihe	TWP2	TWP4	3D-modelling	(hydro)geology of pilot area	use in regional areas	http://www.transgeotherm.eu/publikationen.html
4	unpublished	2015	Peters, A.	Oberflächennahes geothermisches Potential in Thüringen	Thüringer Landesanstalt für Umwelt und Geologie	TWP2	TWP3	potential mapping	use in regional areas	closed-loop system	
5	published	2017	Dahlqvist, P., Epting, J., Huggenberger ,P., García Gil, A	Shallow geothermal energy in urban areas	In Groundwater, Geothermal Modelling and Monitoring at City-Scale (Bonsor et al.). TU1206 COST Sub-Urban WG2 Report (p. 22-38).	TWP2	TWP3	use in urban areas	open-loop system	closed-loop system	https://static1.squarespace.com/static/542bc753e4b0a87901dd6258/t/58aebaeaebbd1a4c4b9ab469/1487846145333/TU1206-WG2.4-005+Groundwater%2C+Geothermal+modelling+and+monitoring+at+city+scale.pdf
6	published	2013	Zosseder, G., Chavez-Kus, L., Somogyi, G., Kotyla, P., Kerl, M., Wagner, B., Kainzmaier, B.	GEPO - Geothermisches Potenzial der Münchener Schotterebene Abschätzung des geothermischen Potenzials im oberflächennahen Untergrund des quartären Grundwasserleiters des Großraum Münchens. GEPO - Geothermal potential of the Munich Gravel Plain Assessment of the geothermal potential in the shallow subsurface of the Quaternary aquifer in the Greater Munich.	19. Tagung für Ingenieurgeologie mit Forum für junge Ingenieurgeologen München 2013	TWP2		field measurements	groundwater	use in urban areas	
7	published	2014	Götzl, G., Fuchsluger, M., Rodler, A., Lipiarski, P., Pfleiderer, S.	Projekt WC-31 Erdwärmepotenzialerhebung Stadtgebiet Wien, Modul 1	Abteilung MA20 - Energieplanung des Magistrats der Stadt Wien	TWP2	TWP3	potential mapping	open-loop system	closed-loop system	https://www.wien.gv.at/stadtentwicklung/energieplanung/stadtplan/erdwaerme/erlaeuterungen.html
8	published	2014	LfULG, PGI	Informationsbroschüre zur Nutzung oberflächennaher Geothermie, Broszura informacyjna na temat stosowania płytkiej geotermii	Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie; Państwowy Instytut Geologiczny - Państwowy Instytut Badawczy, Oddział Dolnośląski (PIG-PIB OD)	TWP4		closed-loop system	quality standards	policy strategies	http://www.transgeotherm.eu/publikationen.html
9	published	2016	Malík, P., Švasta, J., Gregor, M., Bačová, N., Bahnová, N., Pažická, A.	Slovak Basic Hydrogeological Maps at a Scale of 1:50,000 - Compilation Methodology, Standardised GIS Processing and Contemporary Country Coverage	State Geological Institute of Dionýz Štúr Bratislava 2016, Slovak Republic, Slovak Geological Magazine, vol.16, no.1, ISSN 1335-096X	TWP2	TWP1	groundwater	(hydro)geology of pilot area	use in regional areas	
10	published	2016	Bodiš, D., Rapant, S., Kordík, J., Slaninka, I.	Groundwater Quality Presentation in Basic Hydrogeochemical Maps at a Scale of 1:50,000 by Digital Data Treatment Applied in the Slovak Republic	State Geological Institute of Dionýz Štúr Bratislava 2016, Slovak Republic, Slovak Geological Magazine, vol.16, no.1, ISSN 1335-096X	TWP2		groundwater	quality standards	use in regional areas	

ID	literature type	Year/ last access date	Author	Title	Publisher, journal issue, vol., pp.	usefull for WP	linked to WP	Keyword1	Keyword2	Keyword3	web link (if available)
11	published	2016	Fričovský, B., Černák, R., Marcin, D., Benková, K.	A First Contribution on Thermodynamic Analysis and Classification of Geothermal Resources of The Western Carpathians (an engineering approach)	State Geological Institute of Dionýz Štúr Bratislava 2016, Slovak Republic, Slovak Geological Magazine, vol.16, no.1, ISSN 1335-096X	TWP2		heat storage	groundwater	use in regional areas	
12	published	2014	Ditlefsen, C., Sorensen, I., Slott, M., Hansen, M.	Estimation thermal conductivity from lithological descriptions - a new web-based tool for planning of ground-source heating and cooling	Geologcial Survey of Denmark and Greenland Bulletin, vol.31, 55-58	TWP2	TWP1	closed-loop system	thermal conductivity		http://geuskort.geus.dk/termiskejordarter/
13	published	2004	Goodman, R., Jones, G. Ll., Kelly, J., Slowey, E., O'Neill, N.	Geothermal Resource Map of Ireland	Sustainable Energy Authority of Ireland	TWP2	TWP1	closed-loop system	open-loop system	potential mapping	http://maps.seai.ie/geothermal/
14	published	2010	Goodman, R., Jones, G. Ll., Kelly, J.	Methodology in Assessment and Presentation of Low Enthalpy Geothermal Resouces in Ireland	World Geothermal Congress 2010	TWP2	TWP1	field measurements	3D-modelling		
15	published	22.11.2016		ThermoMap		TWP2	TWP1	closed-loop system	potential mapping	(hydro)geology of pilot area	http://www.thermomap-project.eu/
16	published	2012	Abesser, C.	Technical Guide - A screening tool for open-loop ground source heat pump schemes (England and Wales)	BGS and EA	TWP2		open-loop system	potential mapping	groundwater	http://mapapps2.bgs.ac.uk/gshpnational/home.html
17	published	2012	Rajver, D., Pestotnik, S., Prestor, J., Lapanje, A., Rman, N., Janža, M.	Possibility of utilisation geothermal heat pumps in Slovenia (Geothermal resources in Slovenia)	Geological Survey of Slovenia, Bulletin Mineral resources in Slovenia 2012, (165-175)	TWP2		potential mapping	use in regional areas		http://www.geo-zs.si/PDF/PeriodicnePublikacije/Bilten_2012.pdf
18	published	2016	Borović, S., Urumović, K., Terzić, J.	Determination of subsurface thermal properties for heat pump utilization in croatia	Third Congress of Geologists of Republic of Macedonia.	TWP2	TWP3	field measurements	closed-loop system		http://geothermalmapping.fsb.hr
19	published	2015	Holeček J., Burda J., Bílý P., Novák P., Semíková H	Metodika stanovení podmínek ochrany při využívání tepelné energie zemské kůry	GEOTERMAL,TAČR project No.: TB030MZP024	TWP2	TWP4	land-use conflicts			
20	unpublished	2013		Tepelná čerpadla pro využití energetického potenciálu podzemních vod a horninového prostředí z vrtů (Heat pumps and exploitation of the energy potential of underground water and rock environment from wells)		TWP2	TWP4				
21	unpublished	2009	P. Hanžl, S. Čech, J. Čurda, Š. Doležalová, K. Dušek,P. Gürtlerová, Z. Krejčí, P. Kycl, O. Man,D. Mašek, P. Mixa, O. Moravcová, J. Pertoldová,Z. Petáková, A. Petrová, P. Rambousek,Z. Skácelová, P. Štěpánek, J. Večeřa, V. Žáček,	Basic guidelines for the preparation of a geological map of the Czech Republic 1: 25000		TWP2		3D-modelling			
22	published	2016	Götzl, G., Pfleiderer, S., Fuchsluger, M., Bottig, M., Lipiarski, P.	Projekt SC-27, Pilotstudie „Informationsinitiative Oberflächennahe Geothermie für das Land Salzburg (IIOG-S)	Geologische Bundesanstalt	TWP2		closed-loop system	open-loop system	potential mapping	
23	published	2013	van der Meulen	3D geolopgy in a 2D country: perspectives for geological surveying in the Netherlands	Netherlands Journal of Geosiences, 92-4, page 217-241, 2013	TWP2		3D-modelling			

ID	literature type	Year/ last access date	Author	Title	Publisher, journal issue, vol., pp.	usefull for WP	linked to WP	Keyword1	Keyword2	Keyword3	web link (if available)
24	published	2015	LfU	GeoMol - Assessing subsurface potentials of the Alpine Foreland Basins for sustainable planning and use of natural resources. Project Report		TWP2		potential mapping			http://www.geomol.eu
25	published		Agemar (2014, 2016) Gocad-Anwendertreffen	GeoTIS		TWP2	TWP1	3D-modelling	potential mapping		https://www.geotis.de/geotisapp/geotis.php
26	published		LBRG	ISONG: Informationssystem für oberflächennahe Geothermie Baden Württemberg		TWP2	TWP1	3D-modelling	potential mapping	land-use-conflict mapping	http://isong.lgrb-bw.de/
27	published	2007	Joris Ondreka, Maike Inga Rüsgen, Ingrid Stober, Kurt Czurda	ISONG: GIS-supported mapping of shallow geothermal potential of representative areas in south-western Germany—Possibilities and limitations	Renewable Energy 32 (2007) 2186-2200	TWP2	TWP1	potential mapping	closed-loop system	3D-modelling	
28	published	2014	LfULG	Geothermieatlas Sachsen: Allgemeine Erläuterungen zum Kartenwerk der geothermischen Entzugsleistungen im Maßstab 1:50 000 GTK 50	Sächsisches Landesamt für Umwelt, Landwirtschaft und GeologiePillnitzer Platz 3, 01326 Dresden	TWP2	TWP3	potential mapping	closed-loop system	use in regional areas	
29	unpublished			TUNB		TWP2					
30	published	2015	D. Bertermann, H. Klug, L. Morper-Busch	A pan-European planning basis for estimating the very shallow geothermal energy potentials	Renewable Energy 75 (2015) 335-347	TWP2		potential mapping			
31	published	2016	Casasso, Sethi	G.POT A quantitative method for the assessment and mapping of the shallow geothermal potential		TWP2		potential mapping			
32	published	2015	Galgaro et al.	Empirical modeling of maps of geo-exchange potential for shallow geothermal energy at regional scale		TWP2		potential mapping			
33	published		Phillipe Dumas et al.	ReGeoCities Final Report		TWP4		use in urban areas	policy strategies	quality standards	
34	published	2011	Gemelli, Mancini, Longhi	GIS-based energy-economic model of low temperature geothermal resources A case study in the Italian Marche region	Renewable Energy 36 (2011) 2474-2483	TWP2		policy strategies			
35	published	2002	Hamada et al.	Study on underground thermal characteristics by using digital national land information, and its application for energy utilization	Applied Energy 72 (2002) 659-675	TWP2		potential mapping			
36	published	2016	Hein et al.	Potential of shallow geothermal energy extractable by Borehole Heat Exchanger coupled Ground Source Heat Pump systems	Energy Conversion and Management 127 (2016) 80-89	TWP2		potential mapping	closed-loop system		
37	published	2011	Nam, Ooka	Development of potential map for ground and groundwater heat pump systems and the application to Tokyo		TWP2		potential mapping	use in urban areas		
38	published			Adriatic IPA project LEGEND: Low enthalpy geothermal energy demonstration		TWP4		quality standards	policy strategies		http://www.adriaticipacbc.org/login.asp
39	published			Cheap-GSHPs: Cheap and efficient application of reliable ground source heat exchangers and pumps		TWP2	TWP4	quality standards	policy strategies		http://cheap-gshp.eu/

ID	literature type	Year/ last access date	Author	Title	Publisher, journal issue, vol., pp.	usefull for WP	linked to WP	Keyword1	Keyword2	Keyword3	web link (if available)
40	website			COST-Action GABI: Geothermal energy Applications in Buildings and Infrastructure		TWP4		quality standards	potential mapping		https://www.foundationgeotherm.org/
41	website			EGIP: European Geothermal Information Platform		WPC		policy strategies			http://egip.igg.cnr.it/
42	published			FROnT: Fair Renewable Heating and Cooling Options and Trade		TWP4	WPC	policy strategies	quality standards		http://www.front-rhc.eu/
43	website			GEOTeCH: Geothermal Technology for €conomic Cooling and Heating		WPC	TWP3	field measurements	quality standards		http://www.geotech-project.eu/
44	website			Geothermal ERA-NET		TWP1	WPC	use in regional areas	policy strategies		http://www.geothermaleranet.is/
45	published			GEOTRAINET: Geo-Education for a sustainable geothermal heating and cooling market		TWP4	WPC	quality standards			http://geotrainet.eu/
46	website			Green Epile: Development and implementation of a new generation of energy piles		WPC					http://cordis.europa.eu/project/rcn/204589_en.html
47	published			IMAGE: Integrated Methods for Advanced Geothermal Exploration		TWP2	TWP3	field measurements	use in regional areas		http://www.image-fp7.eu/Pages/default.aspx
48	website			ITER: Improving Thermal Efficiency of horizontal ground heat exchangers		WPC		monitoring	field measurements		http://iter-geo.eu/
49	website			ITHERLAB: In-situ thermal rock properties lab		TWP3		field measurements			http://cordis.europa.eu/project/rcn/201131_en.html
50	website			TERRE:Training Engineers and Researchers to Rethink geotechnical Engineering for a low carbon future		WPC		quality standards			http://www.terre-etn.com/
51	website			TESSe2b:Thermal Energy Storage Systems for Energy Efficient Buildings. An integrated solution for residential building energy storage by solar and geothermal resources		TWP4		heat storage	quality standards		http://www.tesse2b.eu/tesse2b/newsTesse2bProject
52	website			TRANSENERGY, legal aspect of transboundary aquifer management		TWP2	TWP4	3D-modelling			http://transenergy-eu.geologie.ac.at/
53	website	2016		GRETA		TWP2	TWP4	quality standards	use in regional areas	policy strategies	http://www.alpine-space.eu/projects/greta/en/home http://www.alpine-space.eu/projects/greta/en/project-results/reports/deliverables
54	website		LfU	IOG Bayern	LfU	TWP2	TWP1	open-loop system	closed-loop system	land-use-conflict mapping	http://www.lfu.bayern.de/geologie/geothermie_iog/
55	website		LBEG	NIBIS, Niedersachsen	LBEG	TWP2	TWP1	potential mapping	land-use-conflict mapping	3D-modelling	http://nibis.lbeg.de/cardomap3/
56	website		lgb-rlp	Rheinland Pfalz	lgb-rlp	TWP2	TWP1	potential mapping	3D-modelling	land-use-conflict mapping	http://www.lgb-rlp.de/karten-und-produkte/online-karten/online-karten-geothermie.html
57	website		LLUR	Schleswig Holstein	LLUR	TWP2	TWP1	potential mapping			

ID	literature type	Year/ last access date	Author	Title	Publisher, journal issue, vol., pp.	usefull for WP	linked to WP	Keyword1	Keyword2	Keyword3	web link (if available)
58	published	Jun 16	Tina Zivec, Elea iC d.o.o., Slovenia	Markovec_USING 3D GEOLOGICAL MODELLING IN CIVIL INDUSTRY	3rd Europeanmeeting on 3D geologicalmodelling	TWP2		3D-modelling			
59	published	2014	S. J. Mathers, R. L. Terrington, C. N. Waters and A. G. Leslie	GB3D – a framework for the bedrock geology of Great Britain	Geoscience Data Journal 1: 30-42 (2014), RMetS	TWP2	TWP1	3D-modelling			
60	published	2011	Ad-hoc-AG Geologie, PK Geothermie	Fachbericht zu bisher bekannten Auswirkungen geothermischer Vorhaben in den Bundesländern		TWP2	TWP4	quality standards	land-use-conflict mapping		http://www.infogeo.de/home/geothermie/dokumente/index_html?sfb=8&sdok_typ=-1&skurzbeschreibung=
61	website		Geologischer Dienst NRW	Portal Geothermie Nordrhein-Westfahlen	Geologischer Dienst NRW	TWP2	TWP1	closed-loop system	land-use-conflict mapping		http://www.geothermie.nrw.de
62	published	2016	GSI	Ground Source Heating/Cooling System Suitability Maps - Open Loop Systems	GSI	TWP2	TWP2	open-loop system	potential mapping		
63	published	2016	GSI	Ground Source Heating/Cooling System Suitability Maps - Closed Loop Systems	GSI	TWP2	TWP2	closed-loop system	potential mapping		
64	published	2017	Jannis Epting, Alejandro García-Gil, Peter Huggenberger, Enric Vázquez-Suñe, Matthias H. Mueller	Development of concepts for the management of thermal resources in urban areas – Assessment of transferability from the Basel (Switzerland) and Zaragoza (Spain) case studies	Journal of Hydrology 548 (2017) 697–715	TWP2	TWP3	use in urban areas	open-loop system	potential mapping	http://www.sciencedirect.com/science/article/pii/S0022169417301993
65	published	2016	Götzl, G., Fuchsluger, M., Steiner, C.	Projekt WC-33 Potenzialkarte für die integrative Planung thermischer Grundwassernutzungen in Aspern Nord	GBA	TWP2	TWP3	use in urban areas	open-loop system	potential mapping	
66	published	2006	Götzl, G., Ostermann, V., Kalasek, R., Heimrath, R., Steckler, P., Zottl, A., Novak, A., Haindlmaier, G., Hackl, R., Shadlau, S., Reitner, H.	GEO-Pot Seichtes Geothermie Potenzial Österreichs. Überregionale, interdisziplinäre Potenzialstudie zur Erhebung und Darstellung des oberflächennahen geothermischen Anwendungspotenzials auf Grundlage eines regelmäßigen Bearbeitungsratsers	OEWAV 5-6/2010, Springer	TWP2	TWP3	closed-loop system	potential mapping		

Annexes

Annex 1 - Assessment sheets regarding open loop systems

Assessment sheet – Mapping low enthalpy geothermal potential of shallow quaternary aquifers in Finland

Please use this sheet for summarizing realized methods and approaches on both national as well as international level. Use one sheet per project / initiative and make sure to upload reports screened for this assessment on the joint knowledge repository, even in case the report is only available in national language!

Please insert information in the blue colored fields.

ID knowledge repository As indicated in register at Own Cloud	1	Reference Please use format: Author, Year, Title, Journal, Publisher	Arola, T., Eskola, L., Hellen, J. and Korkka-Niemi K., 2014, Mapping the low enthalpy geothermal potential of shallow Quaternary aquifers in Finland, Springer

Territorial coverage of study / initiative National – please indicate country; international – please indicate participating countries	Entire country of Finland

Thematic coverage of study / initiative Please tick topics		3D modelling methods with regard to the mapping of utilization potentials and risks
	x	Mapping of potential: open loop systems
		Mapping of potential: closed loop systems
		Mapping of land-use conflicts and risks, environmental impact assessment

Shallow geothermal utilization methods covered by project / initiative Please specify systems (e.g. borehole heat exchanger, groundwater well, horizontal collector)	The project covers open loop systems using double-wells in aquifers under urban or industrial land use.

Executive summary / synopsis of the report Maximum 1000 characters
The main objective of the project was to investigate whether groundwater could provide a shallow geothermal energy resource, and to what extent it could meet the demands for heating buildings in Finland. The provided information should not be used when planning geothermal systems for a single property. The heating potential was estimated based on the flux, temperature and heat capacity of groundwater and the efficiency of heat pumps. The design power of

residential buildings was divided by the groundwater power to determine the ability of groundwater to heat buildings. Approximately 56500 ha of Finnish aquifers are zoned for urban or industrial land use. In total 55 to 60 MW of the heat load could be utilised with heat pumps, meaning that 25% to 40% of annually constructed residential buildings could be heated utilising groundwater in Finland.

Description of applied approach (methods and workflow) for mapping
A novel groundwater energy database, combining the groundwater area and land use information was created using ArcGIS software. To estimate the groundwater flux of the portion of an aquifer with urban or industrial land use, the aquifer's proportional land use ratio was calculated. Energy calculations were performed for each mapped urban and industrial area located inside a groundwater area in three phases: 1) Potential heat power that Finnish aquifers under urban or industrial land use can produce (G) G [W] = $F \cdot \Delta T \cdot S_{Cwat}$ F = groundwater flux [kg/s] = total recharge; ΔT = temperature difference between inlet and outlet in the heat pump [K]; S_{Cwat} = heat capacity of water [J/kg · K] Used values: $\Delta T = 3$ [K], $S_{Cwat} = 4200$ [J/kg · K] 3 K groundwater will usually not freeze if 3 K is extracted, is a conservative figure. 2) Amount of heating power (H) that can be delivered to heat distribution systems by utilising heat pumps Assumptions: 100 % of the amount of heat is exploitable, no heat loss occurs in the evaporator of the heat exchanger and heat from the compressor is delivered efficiently. Since $E = H/COP$ and $H \approx G+E$ with E = electric power [W], G can also be expressed as $G \approx H(1-(1/COP))$. Using the last equation and equation from 1), H can be calculated. H [W] = $F \cdot \Delta T \cdot S_{Cwat}/(1-(1/COP))$ Value used for COP = 3.5 based on literature 3) Surface area of buildings that could be heated using groundwater heating power (A) The design power E_d [W/m²] of detached houses and apartment buildings was simulated with the IDA Indoor Climate and Energy dynamic simulation tool. The heat demands of different locations were simulated based on the four climatic zones in Finland. A [m²] = H/E_d

Description of input data used for mapping Please make a general sketch, no detailed data lists (e.g. hydrogeological maps scale 1:50.000)
- Groundwater areas with an estimated yield of 100 m³/day or more - Land use data above aquifers - Map of climatic zones, mainly based on 30 years of data on annual average air temperatures

Description of output parameters and data-formats of results e.g. printed maps including the scale, GIS based maps, interactive web-systems
- Map with aquifers represented as dots. Colours of dots indicate the categorised amount of heat (G) exploitable. Classes of heat exploitable are: 1 – 100; 100 – 200, 200 – 500, >500 kW - Table of selected groundwater areas ranked according to the amount of heat (G) exploitable

Description of the suitability of the chosen approach for GeoPLASMA-CE Please write a short review about the pros and cons of the chosen approach! Is that approach suitable for GeoPLASMA-CE?
Suitable for GeoPLASMA-CE: Standardized workflow to calculate the heat exploitable from aquifers depending on their land use and the amount of heating power that can be delivered to heat distribution systems.

Assessment sheet – WC 31, Shallow geothermal potential maps, City of Vienna

Please use this sheet for summarizing realized methods and approaches on both national as well as international level. Use one sheet per project / initiative and make sure to upload reports screened for this assessment on the joint knowledge repository, even in case the report is only available in national language!

Please insert information in the blue colored fields.

ID knowledge repository As indicated in register at Own Cloud	7	Reference Please use format: Author, Year, Title, Journal, Publisher	Götzl, G., Fuchsluger M., Rodler F.A., Lipiarski P., Pfleiderer S., 2014, Projekt WC-31, Erdwärmepotenzialerhebung Stadtgebiet Wien, Modul 1

Territorial coverage of study / initiative National – please indicate country; international – please indicate participating countries	City of Vienna

Thematic coverage of study / initiative Please tick topics		3D modelling methods with regard to the mapping of utilization potentials and risks
	x	Mapping of potential: open loop systems
	x	Mapping of potential: closed loop systems
		Mapping of land-use conflicts and risks, environmental impact assessment

Shallow geothermal utilization methods covered by project / initiative Please specify systems (e.g. borehole heat exchanger, groundwater well, horizontal collector)	Closed loop systems: - Borehole heat exchangers (max. depth 300 m) - thermically enhanced construction parts Open loop systems: - Applications using heat pumps or free cooling

Executive summary / synopsis of the report Maximum 1000 characters
The objective of this project, funded by the Municipal Department 20 of the Vienna City Administration, was to analyse the shallow geothermal potential of Vienna and provide shallow geothermal potential maps. The heat conductivity was determined as the crucial parameter for the determination of the potential for closed loop systems. The potential was determined for 3 different depth intervals. The investigation of the shallow geothermal potential for open loop systems included only the uppermost aquifer. The crucial parameter to determine this potential was the

maximum thermal power of a well doublet, depending on the hydrogeological situation.

Description of applied approach (methods and workflow) for mapping

Workflow closed loop systems:

- Derivation of thermal rock properties for existing borehole profiles from literature studies. Borehole profiles were changed into heat conductivity and heat capacity profiles.
- The city area was divided into 22 geologically homogenous areas, based on existing geological maps.
- Pointed information about thermal properties was extrapolated into a citywide map using statistical average. The heat conductivity profile for each homogenous area was determined using statistical average.

Workflow open loop systems:

- A hydrogeological map, scale 1: 25 000, was divided into 14 hydrogeolocially homogenous areas

- The maximum thermal power for virtual well doublets on locations with existing hydrogeolocial information was calculated within the homogenous areas using the following equation:

  $P\ [W] = \Delta T \cdot \langle cp \cdot \rho \rangle \cdot Q$

  ΔT = Difference of temperature between extraction and injection well

  $cp \cdot \rho$ = Volumetric heat capacity of ground water $[J/m^3/K]$

  Q = Discharge of well doublet $[m^3/s]$

  ΔT was set to 5K in a first step. The value was decreased, if the target value of the Rulesheet RB207 had been breached, according to given groundwater temperature time series. RB207 demands a maximum and minimum injection temperature of 20 °C and 5 °C, respectively.

  The maximum admissible discharge (Q) was calculated using the approach of Thiem (1906):

  $Q = kf \cdot (m_{NGW} - 1) \cdot m_{MGW}$

  Kf = hydraulic conductivity [m/s]

  m_{NGW} = thickness of ground water body at low water level

  m_{MGW} = thickness of ground water body at average water level

- The mean average of the maximum thermal power is calculated for each homogenous area.

Description of input data used for mapping

Please make a general sketch, no detailed data lists (e.g. hydrogeological maps scale 1:50.000)

- Geological maps
- Thermal Response Tests
- Characteristic thermal properties according to literature studies (ÖWAV, VDI)
- Borehole profiles
- User data of existing shallow geothermal applications

- Groundwater isolines
- Top Aquifer
- Thickness of “Wienerwaldschotter” (=Aquifer)
- Soil temperatures
- Groundwater Temperatures

Description of output parameters and data-formats of results e.g. printed maps including the scale, GIS based maps, interactive web-systems
All potential maps are accessible via the webviewer of the city of Vienna. A report in a new window opens by clicking on the map. It includes the suitability/power class of the location and provides information whether or not a license for the closed loop systems is necessary. Closed Loop systems - 3 Potential maps for different depth intervals: 30 m, 100 m, 200 m Classification of the potential maps depends on the average heat conductivity: < 1.6 W/m/K Low suitability 1.6 - < 1.9 W/m/K Medium suitability > 1.9 W/m/K High suitability Open Loop systems - Potential map, scale 1:25 000 Classification of the potential map depends on maximum thermal power for well doublets: < 1 kW Open loop systems not recommended 1 kW - < 5 kW Small sized applications after evaluation of local situation possible 5 kW - < 20 kW Medium sized applications after evaluation of local situation possible > 20 kW Large sized applications and local grids after evaluation of local situation possible Water protection areas are included in the map

Description of the suitability of the chosen approach for GeoPLASMA-CE Please write a short review about the pros and cons of the chosen approach! Is that approach suitable for GeoPLASMA-CE?
PROs: The approaches and workflows for closed and open loop systems are considered to be suitable for GeoPLASMA-CE. The project report describes the developed approach in small detail. In order to successfully apply the methodology to GeoPLASMA-CE, detailed (hydro)geological information about the pilot areas has to be accessible.

Assessment sheet –
Geothermal Resource Map of Ireland

Please use this sheet for summarizing realized methods and approaches on both national as well as international level. Use one sheet per project / initiative and make sure to upload reports screened for this assessment on the joint knowledge repository, even in case the report is only available in national language!

Please insert information in the blue colored fields.

ID knowledge repository As indicated in register at Own Cloud	14, 15, 62, 63	Reference Please use format: Author, Year, Title, Journal, Publisher	GSI, 2016, Ground Source Heating/Cooling System Suitability Maps – Open Loop systems

Territorial coverage of study / initiative National – please indicate country; international – please indicate participating countries	Entire country of Ireland

Thematic coverage of study / initiative Please tick topics		3D modelling methods with regard to the mapping of utilization potentials and risks
	x	Mapping of potential: open loop systems
	x	Mapping of potential: closed loop systems
		Mapping of land-use conflicts and risks, environmental impact assessment

Shallow geothermal utilization methods covered by project / initiative Please specify systems (e.g. borehole heat exchanger, groundwater well, horizontal collector)	Open Loop systems for domestic and smaller commercial use. Open Loop systems for larger commercial and industrial processes. Vertical closed loop systems.

Executive summary / synopsis of the report Maximum 1000 characters
The project aimed at identifying the potential resources of geothermal energy in Ireland. Goals of the study were to create a series of geothermal maps for Ireland and present recommendations on the potential for exploitation of geothermal resources in Ireland in the context of international best practice. The maps intend to assist in deciding whether a site is suitable for using ground source heating/cooling systems, and which type is most appropriate for a particular site. Where all maps should be assessed together, since a site may be unsuitable for one type, but highly suitable for another.

Description of applied approach (methods and workflow) for mapping

Open loop

The suitability map is based only on the bedrock and sand/gravel aquifer maps. All aquifers had been divided into the categories seen in the table below, depending mainly on their typical borehole yield range (m^3/d) that can be expected based on known well yields around the country (Geological survey of Ireland wells and springs database).

Groundwater temperature and chemistry are not considered in the suitability classification.

Aquifer category	Typical borehole yield range (m^3/d)	Suitability class		Ground-water flow regime	Ground-water temperature variability
		Domestic & small commercial systems	Large commercial & industrial processes		
Pu – Poor Aquifer - Bedrock which is Generally Unproductive	<20	1	1	Fractured	Low
Pl – Poor Aquifer - Bedrock which is Generally Unproductive except for Local Zones	<50	1	1	Fractured	Low
Ll – Locally important - Bedrock which is Moderately Productive only in Local Zones	50 - 400	3	2	Fractured	Low
Lm – Locally important - Bedrock which is Generally Moderately Productive	100 - >400	5	4	Fractured	Low
Lk – Locally important - Karstified Bedrock	10 - >400	4	3	Diffuse/ Conduit Karstic Flow	Low to high
Lg – Locally important - Sands & gravels	>400 - >1,000	5	4	Intergranular	Very low
Rg – Regionally Important - Extensive sand & gravel	>400 - >1,000	5	5	Intergranular	Very low
Rf – Regionally Important - Fissured bedrock	100 - >400	5	4	Fractured	Low
Rk – Regionally Important - Karstified bedrock	10 - >1,000	4	4	Diffuse/ conduit Karstic Flow	Low to high
Rkc – Regionally Important - Karstified bedrock dominated by conduit flow	10 - >1,000	4	4	Conduit Karstic Flow	Moderate to high
Rkd – Regionally Important - Karstified bedrock dominated by diffuse flow **(& Rf/Rk)**	>400 - >1,000	5	5	Diffuse Karstic Flow	Low to moderate

Temperature maps have however been developed within another study and they are available as additional layer in the webviewer. The second study surveyed or compiled data on warm springs and groundwater temperature trends. In order to map the subsurface temperatures, all available borehole data from previous studies and mineral and oil exploration holes was retrieved. In addition to this, CSA surveyed 32 existing, open boreholes to obtain temperature profiles. The examined holes ranged from 40m to 810m in depth. The temperature profiles were used to extrapolate geothermal gradients to depth and create temperature maps.

The temperatures were modelled using grid modelling software (Mapinfo add-in: Vertical Mapper) within the software Mapinfo. The data points fall primarily within two clusters with scattered data points outside these two regions. In addition, parts of the country had no data available. Natural neighbour interpolation was best suited to model these clustered datasets and all detailed modelling was conducted using this method.

Closed loop

The selected parameter indicating the potential for closed loop systems is the thermal conductivity. The table below outlines the geological factor used in the Vertical Closed Loop suitability maps. Other factors, such as groundwater flow are not factored in to the maps.

Geological factor	Class	Rank
Bedrock thermal conductivity (W/m/K)	> 2.7	Highest
	2.2 - 2.7	↓
	< 2.2	Lowest
Aquifer type	Bedrock aquifer	Highest
	Sand & gravel aquifer	Lowest
Depth to bedrock (subsoil thickness)	< 3 m	Highest
	3-10 m	↓
	> 10 m	Lowest
Subsoil type, moisture content & thermal conductivity	1.7 - 1.8 - 2.4 Wet Sand and Gravels, Till, Alluvium, Lacustrine	Highest
	0.4 Peat, Dry Sand and Gravels and Till	Lowest

The decision tree for the suitability classification for vertical closed loop systems, is shown below. The numbers refer to the suitability classes (see Description of output parameters)

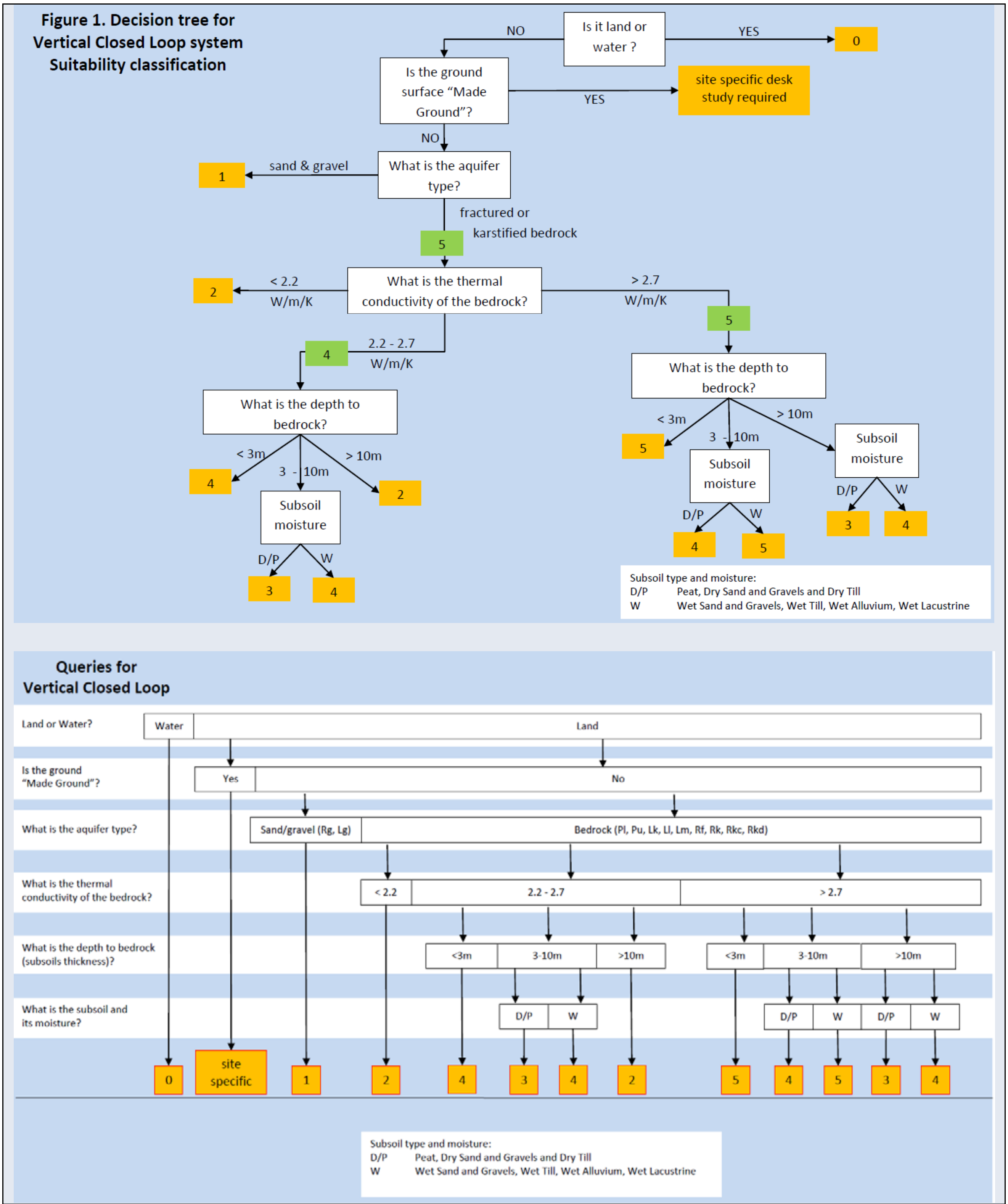

Figure 1. Decision tree for Vertical Closed Loop system Suitability classification

Description of input data used for mapping Please make a general sketch, no detailed data lists (e.g. hydrogeological maps scale 1:50.000)
Open loop - Bedrock aquifer map 1:100.000 - Sand/gravel aquifer map 1:50.000

- Temperature data obtained from previous studies and measurements in open boreholes Closed loop - Bedrock map 1:500.000 - Groundwater recharge map 1:50.000 - Depth to bedrock map 1:40.000 (unpublished)

Description of output parameters and data-formats of results e.g. printed maps including the scale, GIS based maps, interactive web-systems
Scale of the output maps is 1:50.000. Web-viewer including the following maps: - Location of boreholes 100 m - Geological faults - Designated Areas (special protection areas, (proposed) natural heritage areas, special area of conservation) - Geothermal modelled temperatures (10 m, 100 m, 500 m, 1000 m, 2500 m and 5000 m) - 3 suitability maps for geothermal applications (vertical closed loop systems, open loop domestic systems, open loop commercial systems) Classification for all suitability maps: - 5 Highly suitable - 4 Suitable - 3 probably suitable (unless proved otherwise/site assessment required) - 2 possibly unsuitable (site assessment required) - 1 generally unsuitable (site assessment required)

Description of the suitability of the chosen approach for GeoPLASMA-CE Please write a short review about the pros and cons of the chosen approach! Is that approach suitable for GeoPLASMA-CE?
PROs: - Two separate maps were produced for small and commercial use - Simple approach, Maps were derived primarily from Geological/hydrogeological maps - Display of designated Areas - Different maps for open loop domestic and open loop commercial systems might be helpful, if the potentials for the two systems are very different in the pilot areas of GeoPLASMA-CE CONs: - The Classification of the suitability within 5 classes might be too high. A lower number e.g. 3 should be sufficient, in order to keep the map easily understandable.

Assessment sheet – ThermoMap

Please use this sheet for summarizing realized methods and approaches on both national as well as international level. Use one sheet per project / initiative and make sure to upload reports screened for this assessment on the joint knowledge repository, even in case the report is only available in national language!

Please insert information in the blue colored fields.

ID knowledge repository As indicated in register at Own Cloud	13	Reference Please use format: Author, Year, Title, Journal, Publisher	Project ThermoMap (2010-2013) Coordinator: Bertermann, D.

Territorial coverage of study / initiative National – please indicate country; international – please indicate participating countries	Entire Europe and 14 test areas in Austria, Belgium, France, Germany, Greece, Hungary, Iceland, Romania and United Kingdom

Thematic coverage of study / initiative Please tick topics		3D modelling methods with regard to the mapping of utilization potentials and risks
		Mapping of potential: open loop systems
	X	Mapping of potential: closed loop systems
		Mapping of land-use conflicts and risks, environmental impact assessment

Shallow geothermal utilization methods covered by project / initiative Please specify systems (e.g. borehole heat exchanger, groundwater well, horizontal collector)	Vertical/horizontal and special forms of vertical heat collectors

Executive summary / synopsis of the report Maximum 1000 characters
The ThermoMap project focuses on the mapping of the very shallow geothermal energy potentials (vSGP) in Europe. The 12 project partners from 9 EU member states defined one or two test sites in each country (total of 14 test areas). The “ThermoMap MapViewer” is intended for the public, planners and engineers, public bodies and scientists to give an information about local shallow geothermal conditions.

Description of applied approach (methods and workflow) for mapping
1) The project harmonises and analyses already existing data (geological, hydrogeological, soil, climate and relief geodata) with standardised methods to calculate a value for the geothermal potential on three different low depth levels and on a large to medium scale. 0 – 3 m: for horizontal geothermal heat collectors

3 – 6 m: for vertical geothermal heat collectors
6 – 10 m: for special forms of vertical heat collectors
The analysis of the geodata will be performed in a GIS-environment with standardised methods, valid for all participating countries.

The heat conductivity is calculated based on the Kersten (1949) formula, using soil data (moisture state, grain size and density) and climate data (precipitation and air temperature).
Classification of heat conductivity:

- > 1.2 W/mK: High
- 1.1 – 1.2 W/mK: Medium high
- 1.0 – 1.1 W/mK: Medium
- 0.9 – 1.0 W/mK: Medium low
- < 0.9 W/mK: Low

All areas with legal constraints (nature protection zone, water protection zone, flood area), a slope > 15°, permafrost or a certain soil type (e.g. planosol, gleysol) are classified to have limited usability.
Map areas containing hard rock within the first depth layer are considered unsuitable for very shallow geothermal system.

2) "vSGP Calculator": The calculation function loads all available data from the European Outline Map for a specified map point to the calculator. The user can utilise the existing data or amend it with own data. Compared to the accuracy level of the European Outline Map, the calculator offers the possibility to reach an even greater level of accuracy as in the test areas for a single map location.

Description of input data used for mapping
Please make a general sketch, no detailed data lists (e.g. hydrogeological maps scale 1:50.000)

- Slope
- Annual temperature
- Annual precipitation
- Water table
- Thickness of the softrock zone
- Soil type (WRB classification)
- Grain size at three depth levels (USDA classification)
- Heat conductivity at three depth levels

Description of output parameters and data-formats of results
e.g. printed maps including the scale, GIS based maps, interactive web-systems

1) "ThermoMap MapViewer" includes information for the suitability of very shallow geothermal systems for Europe (1:250000) and more detailed information in selected test areas on cadastral parcel level (from 1:5000 to 1:40000). Locations within the test areas are classified as limited usable, suitable and not suitable regarding the use of very shallow geothermal systems. Additionally layers with background information (protection zones, water bodies, softrock thickness, slope, annual mean temperature and annual precipitation) are available.

Different info tools display interpreted information in an info box, as a table or as a printed report enriched with map details and diagrams.

2) "Calculator" can be used to improve estimations for locations on the European Outline Map and also outside of the MapViewer for calculating the vSGP in non-european countries.

Description of the suitability of the chosen approach for GeoPLASMA-CE Please write a short review about the pros and cons of the chosen approach! Is that approach suitable for GeoPLASMA-CE?
PROs: Structure of the web viewer: - different info tools - background parameters as layers - Only areas with suitable or limited usability are coloured. CONs: - The depths are too low for GeoPLASMA-CE. - Too many classes of heat conductivity (medium high and medium low unnecessary) Overall this is a best practice example, with useful information about the processing of geodata and the structure of the webviewer.

Assessment sheet – A screening tool for open-loop ground source heat pump schemes (England and Wales)

Please use this sheet for summarizing realized methods and approaches on both national as well as international level. Use one sheet per project / initiative and make sure to upload reports screened for this assessment on the joint knowledge repository, even in case the report is only available in national language!

Please insert information in the blue colored fields.

ID knowledge repository As indicated in register at Own Cloud	16	Reference Please use format: Author, Year, Title, Journal, Publisher	Abesser, C., 2012, Technical Guide - A screening tool for open-loop ground source heat pump schemes (England and Wales), British Geological Survey

Territorial coverage of study / initiative National – please indicate country; international – please indicate participating countries	England and Wales

Thematic coverage of study / initiative Please tick topics		3D modelling methods with regard to the mapping of utilization potentials and risks
	x	Mapping of potential: open loop systems
	x	Mapping of potential: closed loop systems
		Mapping of land-use conflicts and risks, environmental impact assessment

Shallow geothermal utilization methods covered by project / initiative Please specify systems (e.g. borehole heat exchanger, groundwater well, horizontal collector)	Primarily open-loop systems, secondarily closed loop systems

Executive summary / synopsis of the report Maximum 1000 characters
This methodology was developed by the BGS to produce a screening tool for assessing the suitability for open-loop ground source heat pump installation (>100 kW thermal capacity) in England and Wales to increase confidence at the early planning stage and to encourage the uptake of open-loop GSHP technology. The screening tool gives planners and developers an initial indication of the depth, productivity and quality of potential aquifers that exist in a given area.

Description of applied approach (methods and workflow) for mapping

The GSHP screening tool consists of a set of data layers in GIS format and database format. The layers are based on existing national scale data sets.
The screening map was derived by combining the layers bedrock aquifer potential and depth to source.

Description of input data used for mapping
Please make a general sketch, no detailed data lists (e.g. hydrogeological maps scale 1:50.000)

- Bedrock Aquifer map
- Depth to source
- Protected areas
- Groundwater chemistry data

Description of output parameters and data-formats of results
e.g. printed maps including the scale, GIS based maps, interactive web-systems

Screening Map with scale of 1:250 000 in webviewer shows areas “favourable” and “less favourable” for open-loop systems. In “Less favourable” areas closed-loop GSHP are indicated as possible suitable alternative.
Ares, which meet the basic requirements for open-loop GSHP installations, are mapped as “favourable”. Therefor aquifers with yields of at least 1 l/s have to be present within 300 m beneath the topographic surface.

Clicking on the map allows further exploration of the underlying data layer for “favourable” areas. The following information is provided:

- Bedrock Aquifer including available discharge. Link to bedrock map
- Depth to source. Link to source map
- Protected areas. Link to protected areas
- Existing maximum licensed abstraction in m^3/day
- Groundwater chemistry:
  - Langelier saturation index
  - Ryznar stability index
  - Larson-Skold corrosive Index
  - Iron

The Bedrock Aquifer potential layer was derived from the 1:250000 map of geological bedrock formations. Each unit was attributed to its potential of providing

- No suitable aquifer (including all aquifers with productivity < 1 l/s)
- Moderate aquifer (1-6 l/s)
- Good aquifer (>6 l/s)

Given that the depth to source was ≤ 300m

“Source” refers to the uppermost aquifer that is present at any location. It does not necessarily represent the depth to the water table, but in some areas refers to the thickness of the deposits (e.g. confining rock formations) that have to be penetrated before reaching the aquifer.

“Groundwater chemistry” gives important information, whether conditions, which might affect well performances and the life of the heat exchanger, are to be expected. The tendency of the water to form/dissolve calcium carbonate scale, the corrosiveness of the groundwater and the potential for encrustation associated with

high iron concentration are provided.

Description of the suitability of the chosen approach for GeoPLASMA-CE Please write a short review about the pros and cons of the chosen approach! Is that approach suitable for GeoPLASMA-CE?
PROs - Easy approach for open-loop systems, "favourable" areas only depend on discharge and depth to source. CONs - Unsuitable scale of potential map (1:250 000) - No detailed information about suitability of closed-loop systems. - No overlapping areas for both open- and closed-loop systems.

Assessment sheet – utilization of geothermal heat in Slovenia

Please use this sheet for summarizing realized methods and approaches on both national as well as international level. Use one sheet per project / initiative and make sure to upload reports screened for this assessment on the joint knowledge repository, even in case the report is only available in national language!

Please insert information in the blue colored fields.

ID knowledge repository As indicated in register at Own Cloud	17	Reference Please use format: Author, Year, Title, Journal, Publisher	Rajver, D., Pestotnik, S., Prestor, J., Lapanje, A., Rman, N., Janža, M., 1992: Possibility of utilisation geothermal heat pumps in Slovenia (Geothermal resources in Slovenia). Geological Survey of Slovenia, Bulletin Mineral resources in Slovenia 2012, (165-175)

Territorial coverage of study / initiative National – please indicate country; international – please indicate participating countries	National - Slovenia

Thematic coverage of study / initiative Please tick topics		3D modelling methods with regard to the mapping of utilization potentials and risks
	x	Mapping of potential: open loop systems
	x	Mapping of potential: closed loop systems
		Mapping of land-use conflicts and risks, environmental impact assessment

Shallow geothermal utilization methods covered by project / initiative Please specify systems (e.g. borehole heat exchanger, groundwater well, horizontal collector)	Groundwater heat pumps, Ground-coupled heat pumps with vertical or borehole heat exchangers

Executive summary / synopsis of the report Maximum 1000 characters
On the map, the territory of Slovenia is divided into five categories according to to the most commonly used geothermal systems: open loop, closed loop – vertical, closed loop horizontal. Groundwater heat pumps are most commonly suitable in lowlands where young Plio-Quaternary unconsolidated and loose sediments are developed, appropriate also in the

areas of terrestrial and deltaic sediments of Neogene and Plio-Quaternary age. Ground-coupled heat pumps with vertical or borehole heat exchangers (BHEs) are often the best choice in parts of central, southern, and western Slovenia that display a diverse range of rocks, either clastic (sandstone, silt) or carbonate (limestone, dolomite). Ground-coupled heat pumps with vertical and horizontal collectors are most often the best choice in areas with clastic or even metamorphic and igneous rocks, and also suitable in areas characterized by flysch and other deep marine. Carbonates as well as metamorphic and igneous rocks may be unsuitable for larger BHE fields.

Description of applied approach (methods and workflow) for mapping
Simple approach of estimating possibility of using geothermal heat pumps based on hydrogeological conditions of the territory of Slovenia. Based on geological and hydrogeological maps, the country was divided into the following 5 categories: 1. Most commonly vertical collectors 2. Most commonly groundwater heat pumps 3. Most commonly vertical/horizontal collectors 4. Often groundwater heat pumps 5. Most commonly unsuitable for larger BHE fields

Description of input data used for mapping Please make a general sketch, no detailed data lists (e.g. hydrogeological maps scale 1:50.000)
Hydrogeological map of Slovenia, scale 1:250.000 Geological map of Slovenia

Description of output parameters and data-formats of results e.g. printed maps including the scale, GIS based maps, interactive web-systems
GIS based map

Description of the suitability of the chosen approach for GeoPLASMA-CE Please write a short review about the pros and cons of the chosen approach! Is that approach suitable for GeoPLASMA-CE?
Simple approach which could be used just in preliminary studies on national or regional level

Assessment sheet – SC 27, Shallow geothermal potential, State of Salzburg

Please use this sheet for summarizing realized methods and approaches on both national as well as international level. Use one sheet per project / initiative and make sure to upload reports screened for this assessment on the joint knowledge repository, even in case the report is only available in national language!

Please insert information in the blue colored fields.

ID knowledge repository As indicated in register at Own Cloud	22	Reference Please use format: Author, Year, Title, Journal, Publisher	Götzl, G., Pfleiderer, S., Fuchsluger, M., Bottig, M., Lipiarski, P., 2016, Projekt SC-27, Pilotstudie „Informationsinitiative Oberflächennahe Geothermie für das Land Salzburg (IIOG-S), GBA

Territorial coverage of study / initiative National – please indicate country; international – please indicate participating countries	State of Salzburg

Thematic coverage of study / initiative Please tick topics		3D modelling methods with regard to the mapping of utilization potentials and risks
	x	Mapping of potential: open loop systems
	x	Mapping of potential: closed loop systems
		Mapping of land-use conflicts and risks, environmental impact assessment

Shallow geothermal utilization methods covered by project / initiative Please specify systems (e.g. borehole heat exchanger, groundwater well, horizontal collector)	Closed loop systems: - Borehole heat exchangers Open loop systems: - Groundwater heat pumps

Executive summary / synopsis of the report Maximum 1000 characters
This project is a pilot study for the development of a digital information system for shallow geothermal applications in the state of Salzburg, Austria. The objectives of the project were to create geothermal potential maps for ground water heat pumps and borehole heat exchangers in the areas of permanent settlement and to support the government of Salzburg to compile concepts for the practical application of this study's products.

The initial approach included potential maps, scale 1:200 000, which were intended to be made available via web viewer and as printable maps. This idea was discarded for different reasons and instead the query for a location should create reports, providing the information about shallow geothermal potential.

Description of applied approach (methods and workflow) for mapping

Closed loop systems

- The bottom line of each sediment basin was defined, using geological maps, elevation model and borehole profiles.
- Based on the geological maps a simplified geological map without sediments of the basin was derived, to estimate the heat conductivity below the basin.
- Based on these two layers a map for heat conductivity was generated, using heat conductivity values from literature studies (VDI4640, data compilation of GBA)

Open loop systems

The potential for thermal use of shallow groundwater was divided into two sub-potentials (hydraulic and thermic sub-potential).

- <u>Thermic sub-potential:</u>
  The thermic sub-potential is determined from the available temperature difference between ground water and injection temperature of the geothermal application. This also equals the thermic groundwater potential. The guideline ÖWAV 207 limits the temperature changes of the groundwater resulting from its thermal use. Considering these limitations the thermic groundwater potential (=temperature difference between extraction (T_e) and injection well (T_i)) can be written as:

  $$\Delta T = \left| T_e - T_i \right|_{5°C}^{20°C} \right| \leq 5°C$$

- <u>Hydraulic sub-potential:</u>
  The hydraulic sub-potential is derived from the maximum discharge available. The discharge available depends on the hydraulic conductivity and the thickness of the groundwater, according to the chosen approach. The hydraulic slope, depth to the water table and well geometry are excluded. The discharge available (Q) is calculated using Thiem's approach:

  $$Q = \pi \cdot kf \frac{5 \cdot H_{MGW}^2}{9 \cdot lnR} \; [m^3/s]$$

  Kf = hydraulic conductivity [m/s]
  H_{NGW} = hydraulic active thickness of groundwater body at low water level
  R = hydraulic range. $R = 3000 \cdot \left(\frac{H_{MGW}}{3}\right) \cdot \sqrt{kf}$

- <u>Technical application potential</u>:
  The total thermal potential represents the technical application potential and is derived from the combination of the two sub-potentials:
  P [W] = $\Delta T \cdot \langle cp \cdot \rho \rangle \cdot Q$
  ΔT = Difference of temperature between extraction and injection well
  $cp \cdot \rho$ = Volumetric heat capacity of ground water [$J/m^3/K$]

Q = Discharge of well doublet [m³/s] The licensed discharges were used as auxiliary quantity to determine the technical application potential for locations where the hydraulic sub-potential could not be calculated due to missing data.

Description of input data used for mapping Please make a general sketch, no detailed data lists (e.g. hydrogeological maps scale 1:50.000)
Closed loop systems - Geological maps of Salzburg - Borehole profiles - Elevation model - Soil temperatures - Thermal Response Tests - Literature compilation of heat conductivities Open loop systems - Licensed discharges for peak loads of existing applications - Literature compilation of hydraulic conductivities - Hydrogeological maps

Description of output parameters and data-formats of results e.g. printed maps including the scale, GIS based maps, interactive web-systems
The outputs of this project have not been implemented in a web based information system until now. Information about the following parameters, which are considered as crucial for the determination of the shallow geothermal potential, has been compiled on scale 1: 200 000. Closed loop systems - Heat conductivity map (depth: 0 – 100 m) - Soil temperature map Using this information and the geometry, material, and operation of method of the borehole heat exchanger, it is possible to determine the best design of the closed loop system. Open loop systems - Outline of hydrogeologically suitable areas - Hydraulic sub-potential: Maximum discharge for well doublets - Thermic sub-potential: Maximum temperature difference for well doublets - Technical application potential: Maximum power for well doublets

Description of the suitability of the chosen approach for GeoPLASMA-CE Please write a short review about the pros and cons of the chosen approach! Is that approach suitable for GeoPLASMA-CE?
PROs The developed approach of this project is considered to be very good for the creation of shallow geothermal potential maps. Heat conductivity values of different rock types are considered.

CONs

Although the depth to 100 m is sufficient for standard BHEs, another map of the heat conductivity for an additional depth interval (eg. – 200m) would be good extension.

The hydraulic conductivity is the most sensitive parameter for the developed approach for open loop systems. Therefore this approach is only suitable for pilot areas, where the hydraulic conductivity is known well.

estimate the annual soil temperatures based on monitoring station is commonly used and can also be applied in GeoPLASMA-CE. However, the correlation between the annual soil temperature and the surface elevation is also depending on the climatic constraints and may not be suited for areas with a high relief. One should consider to create interpolation functions for the soil temperature only for homogeneous regions from a climatic point of view.

Assessment sheet for methods and approaches for potential and risk mapping on shallow geothermal use based on existing projects and initiatives

Please use this sheet for summarizing realized methods and approaches on both national as well as international level. Use one sheet per project / initiative and make sure to upload reports screened for this assessment on the joint knowledge repository, even in case the report is only available in national language!

Please insert information in the blue colored fields.

ID knowledge repository As indicated in register at Own Cloud		Reference Please use format: Author, Year, Title, Journal, Publisher	

Territorial coverage of study / initiative National – please indicate country; international – please indicate participating countries	

Thematic coverage of study / initiative Please tick topics		3D modelling methods with regard to the mapping of utilization potentials and risks
		Mapping of potential: open loop systems
		Mapping of potential: closed loop systems
		Mapping of land-use conflicts and risks, environmental impact assessment

Shallow geothermal utilization methods covered by project / initiative Please specify systems (e.g. borehole heat exchanger, groundwater well, horizontal collector)	

Executive summary / synopsis of the report Maximum 1000 characters

Description of applied approach (methods and workflow) for mapping

Description of input data used for mapping Please make a general sketch, no detailed data lists (e.g. hydrogeological maps scale 1:50.000)

Description of output parameters and data-formats of results e.g. printed maps including the scale, GIS based maps, interactive web-systems

Description of the suitability of the chosen approach for GeoPLASMA-CE Please write a short review about the pros and cons of the chosen approach! Is that approach suitable for GeoPLASMA-CE?